APPENDIX B

Technology Trends

Return to Appendices

Connectivity Technology Trends
Table of Contents

Return to Appendices

Trends in Connectivity Technology
(Technology Overview)

Abstract:

Less than 10 years ago technology to link two sites was limited to the telephone company for two-way voice and data and off air television or the cable company for one-way video. We now see an expanded range of connectivity alternatives from multiple vendors. This paper briefly discusses the major types of connectivity technology. More comprehensive discussions are provided in later sections of this document.

Introduction

As recently as 1990, the two-way communications links available within a county or metropolitan area were oriented toward the telephone company using T1, Fractional T1, ISDN or slower 56 Kbps links. The local cable television company provided 30 to 40 channels of one-way video entertainment and no data related services. Access to the Internet was via a telephone dial-up link that connected at 28.8 Kbps on a good day. Today this picture has been radically altered by the addition of multiple types of technology at a wide variety of price points.

Telephone Links

The telephone company connectivity technology has moved from high-priced leased T1 links to more affordable Digital Subscriber Line (xDSL) links. Even telephone dial-up links have changed with the introduction of new hardware that can connect almost at the speed of the older 56 Kbps leased data line.

The telephone companies have reduced pricing on most services and increased the number of services offered. A T1 line that used to cost over a $1,000 now may cost as little as $100 when purchased in quantity. xDSL-based links can now share a line with voice traffic or, on a dedicated line, can provide data throughput exceeding that of a T1 line.

More telephone companies are adding fiber optics to the heart of their networks to reduce the length of copper cable in the path between central office and phone handset. This infrastructure upgrade improves the reliability of the network and allows more high-speed services to be offered to the telephone company customer.

The telephone companies have to deal with a changed competitive landscape. For example, AT&T is no longer considered to be a dominant vendor of long distance service and SBC considers AT&T, MCI and the cable companies to be threats to their local telephone and data business.

Return to Appendices

Cable Television

The cable television companies have used the newest connectivity technology to make great improvements in their systems. About 10 years ago a cable connection would provide only 30 to 40 analog video channels and the poor reliability of their systems became legendary. Over the past five years a large percentage of cable companies have added fiber optic technology to their systems. This has increased reliability, increased bandwidth and expanded the services offered by these companies. The modern cable company now provides more than 70 analog channels of video, possibly hundreds of digital video channels, digital video disk (DVD) quality music, video on demand, voice telephone and high-speed Internet access.

These significant upgrades to cable company infrastructure and service mix have resulted in the residential user that wants high-speed Internet service now considering the cable modem and the local cable company as the high performance connectivity solution of choice.

Satellite Companies

An emerging connectivity technology for the consumer and small business is satellite-based connectivity. High-speed Internet service is available from DirecTV and Starband for prices and speeds that are similar to xDSL links. This service is ideal for rural users who cannot obtain service from any other vendor. With a nationwide footprint for services, satellite-based connectivity technology has a substantial potential market. However, the upfront cost for the satellite equipment, latency induced by the distance to the satellite, and little meaningful marketing activity make high-speed satellite-based connectivity a slow growing technology.

Utility Power Companies

The utility power companies are an emerging provider of high-speed connectivity services using Broadband over the Power Line (BPL). Their substantial existing infrastructure coupled with BPL provides these companies with the potential to supply a wide range of connectivity services. The potential for this wide range of connectivity offerings over existing plant makes a very attractive business case for the utility power companies. Combined revenues from providing webcam security, high-speed Internet, automated meter reading, demand management and other services should help justify the installation of this BPL technology.

Wireless Systems

Wireless systems have become a dominant form of connectivity technology. Fixed wireless, LAN based wireless used in the external environment, and mobile wireless (mainly the cell phone-oriented systems) will continue to revolutionize the way businesses and their customers communicate.

Fixed wireless systems continue to expand at a rapid pace. Prices have dropped on the most common 802.11 systems (WiFi) to the point where an access point costs $40 and an interface card costs $20. The pricing of equipment utilizing newer fixed wireless standards that provide increased speeds, such as 802.16 (Wi-Max), and additional functionality are anticipated to follow this price performance trend.

LAN-based wireless systems are used by many in the external environment. The antenna systems are changed to support point-to-point links between buildings and one-to-many links supporting wireless ISP applications. Over time the technology will change to adopt the newer standards-based equipment that is optimized for the external environment.

Return to Appendices

The cell phone providers are beginning to implement connectivity technology allowing for higher speed data transfer. The largest five vendors are in the process of implementing mobile data-oriented networks that will provide Internet connectivity comparable to the fastest current dial-up connections at a throughput rate of about 50 Kbps.

Emerging Technologies

New technologies are emerging that will provide greater bandwidth to many users. Fiber-to-the-home (FTTH), now called fiber-to-the-premises (FTTP), and new types of wireless connectivity technology may lead to significant changes in the way we communicate.

More importantly, the various types of technology are converging towards one ubiquitous interconnected fabric. These merging technologies are moving us towards a new environment of seamless communications.

For permanent links, the cost of fiber optic components and related hardware has decreased to a point where fiber optic connectivity is only marginally more expensive than other technologies for new installations. The increased use of fiber-based connectivity technology will allow converged services providing telephone, high-speed Internet, video programming and other services over one fiber link utilizing only two fibers.

Wireless connectivity technology is making great advances in ability to carry more content with less interference. New ultrawideband connectivity technology has the capability to provide LAN like bandwidth over short ranges. When combined with FTTP, this increase in short range bandwidth can be used to provide broadband connectivity throughout the home without the requirement for the installation of expensive wires in the walls.

A convergence in connectivity technology is being planned that will provide 'smart' connectivity that is aware of the connectivity technology that might be available at a given location. In the office, you may plug your laptop into the existing wired network and enjoy a Gigabit Ethernet link. In your car, use the high capacity connection through your cell phone adapter for connectivity. In rural areas outside the range of cell phones, use a mobile antenna to connect to a satellite-based high-speed link. At the airport, make use of the wireless Hotspot and get Internet access and your e-mail at hard-wired speeds. Standardized ways to provide connectivity across technology types and across multiple locations are actively under discussion by the standards groups in the United States and Europe.

Return to Appendices

Introduction to Digital Subscriber Line (DSL)-Based Data Networks

Abstract:

Digital Subscriber Line, also known as xDSL technology, has extended the life of the existing unshielded twisted pair cable plant that provide telephone to our homes and businesses. This technology provides high-speed data access with a range of speeds and distances over telephone cable. This allows the telephone companies to provide services that require high-speed always-on connected service such as high-speed Internet and on-demand content. This paper will describe the nature of xDSL service and possible directions for the future of this technology.

Introduction

Unshielded twisted pair cable (UTP) was invented by Alexander Graham Bell [1] as a technique to allow many twisted pair to be bundled into a larger cable. This cabling approach has been used to support telephone service throughout the United States for over 100 years. The extensive infrastructure that is in place providing ubiquitous links for voice communications can be configured to also support high-speed data communications by using Digital Subscriber Loop technology.

DSL technology is being used to bring high-speed communications services over the same UTP wire that supports voice communications. DSL is a form of broadband service as it uses different frequencies to provide service. Voice communications uses the frequency bands below four kilohertz. DSL uses frequencies above the voice conversation, from 25 kilohertz to 1,000 kilohertz, when both voice and data share the same wire. Other approaches are possible depending upon the speeds required, length of the line and number of conductors that are available in the local loop.

The limiting characteristic of DSL technology is crosstalk and noise from external sources, with radio frequency interference as one example. Crosstalk is the characteristic interference caused by multiple similar traffic streams interacting when being transported in a larger multiconductor cable. At some low level, traffic from an adjacent pair causes interference between two or more pairs of wire. Interference must be considered in the design of the overall technology of the system, such as using different signaling and modulation methods. This interference limits the speed and distance of the link for each flavor of xDSL.

Some of the varieties of DSL are summarized:

ADSL, Asymmetric DSL

Asymmetric DSL is primarily used to provide data service on the same pair of wire as an existing telephone voice line. The characteristics include:

1. Uses one pair of wire
2. Bit rate ~1 Mbps upstream
3. Bit rate ~8 Mbps downstream
4. Bandpass 25-138 KHz upstream
5. Bandpass 15-1,104 KHz downstream

Return to Appendices

G.lite, Splitterless ADSL

G.Lite is a variation of Asymmetric DSL used to bring high-speed data service over the same telephone line as voice. The characteristics include:

1. Uses one pair of wire
2. Bit rate ~1 Mbps upstream
3. Bit rate ~1.5 Mbps downstream
4. Bandpass 25-138 KHz upstream
5. Bandpass 15-552 KHz downstream

RADSL, Rate Adaptive DSL

Rate Adaptive DSL is ADSL using a different modulation approach. The characteristics include:

1. Uses one pair of wire
2. Bit rate ~1 Mbps upstream
3. Bit rate ~8 Mbps downstream
4. Bandpass 25-138 KHz upstream
5. Bandpass 15-1104 KHz downstream

HDSL, High-bit-rate DSL

High-bit-rate DSL provides similar performance to a T1 line. It is symmetrical, equal speeds in both directions, and uses two pair of wire, one pair for transmit and one pair for receive. The characteristics include:

1. Uses two pair of wire
2. Bit rate=1.544 Mbps upstream
3. Bit rate=1.544 Mbps downstream
4. Bandpass 0-370 KHz upstream
5. Bandpass 0-370 KHz downstream

HDSL2, Second Generation HDSL

High-bit-rate DSL 2 is a newer variation of HDSL using a different modulation approach. The characteristics include:

1. Uses one pair of wire
2. Bit rate=1.544 Mbps upstream
3. Bit rate=1.544 Mbps downstream
4. Bandpass=0-300 KHz upstream
5. Bandpass=0-440 KHz downstream

HDSL4, Second Generation HSDL

High-bit-rate DSL 4 is a newer variation of HDSL using a different modulation approach. The characteristics include:

1. Uses two pair of wire
2. Bit rate=1.544 Mbps upstream
3. Bit rate=1.544 Mbps downstream
4. Bandpass=0-130 KHz upstream

Return to Appendices

5. Bandpass=0-440 KHz downstream

SDSL, Symmetric DSL

Symmetric DSL provides high-speed symmetrical service using one dedicated UTP pair. It is primarily used to provide services to the business community. The characteristics include:

1. Uses one pair of wire
2. Bit rate up to 2.32 Mbps upstream
3. Bit rate to 2.32 Mbps downstream
4. Bandpass=0-700 KHz upstream
5. Bandpass=0-700 KHz downstream

G.SHDSL, International SDSL

G.SHDSL is an international standard version of Symmetric DSL. It is designed to incorporate the features of Asymmetric DSL and Symmetric DSL and will transport T1, E1, ISDN and ATM signals. The characteristics include:

1. Uses one or two pairs of wire (two pair provides greater distance capability)
2. Bit rate to 2.32 Mbps upstream
3. Bit rate to 2.32 Mbps downstream
4. Bandpass=0-400 KHz upstream
5. Bandpass=0-400 KHz downstream

VDSL, Very-high-bit-rate DSL

Very-high-bit-rate DSL works in a range over short distances, usually between 1,000 and 4,500 feet (300 – 1,500 meters), of twisted pair copper wire. The shorter the distance of the link, the faster the connection rate. The characteristics include:

1. Uses one pair of wire
2. Bit rate ~13 Mbps upstream
3. Bit rate ~22 Mbps downstream
4. Bandpass 25 KHz-12 MHz upstream
5. Bandpass 25 KHz-12 MHz downstream

xDSL Cable Plant Components

The typical DSL system is composed of several key large elements:

Headend or Central Office

A Digital Subscriber Line Access Multiplexer (DSLAM) provides the link between the voice network and data network to the copper UTP running to the subscriber location. A DSLAM separates the voice-frequency signals from the high-speed data traffic and controls and routes digital subscriber line (xDSL) traffic between the subscriber's end-user equipment (router, modem, or Network Interface Card [NIC]) and the network service provider's network.

Return to Appendices

Various configurations consist for this device. Figure 1 shows a DSLAM that is placed in the central office. Other variations exist for remote placement where a conversion must take place between a fiber optic link running from the central office and the unshielded twisted pair wire running from the transition point to the subscriber premises.

Figure 1

Local Node or Point of Presence

Each subscriber premises will have a termination module, a DSL router and connecting components, between the DSL signaling and the internal data network in the home or business.

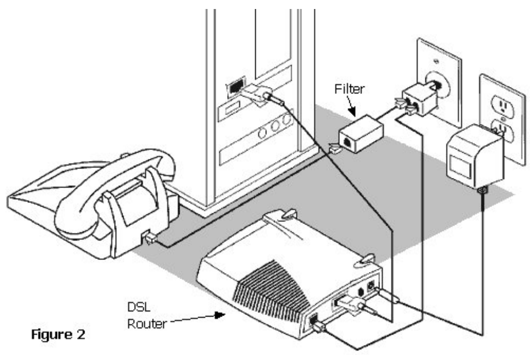


Figure 2

Figure 2 illustrates the typical connection approach used in the home or small business for an ADSL line. The key connections shown are:

- The telephone connects to the telephone line through a filter. The filter removes the high frequency data signaling that may interact with the components within the telephone and cause noise. This filter's location depends upon the design used by the DSL provider. Some providers place the filter in a box on the outside of the building splitting service into telephone and data. A new data line is run from the box to the desired DSL router location. The advantage of this approach is no filters need to be placed on each telephone. The disadvantage is the user must install a new cable through the building. This may be challenging in residential property where all spaces are finished with the existing cabling concealed within the walls.

- A splitterless design places a filter at each telephone as shown in Figure 2. The advantage of the splitterless approach is that the DSL router may be placed at any point within the building where a telephone is currently connected. The disadvantage is filters must be placed on all of the existing telephones when DSL service is installed.

- The local Personal Computer (PC) connects to the DSL router. The interface between the two devices is either Ethernet or a USB link.

Return to Appendices

- The DSL router is the link between the telephone line and the local computer. It converts the signaling present in an analog form on the telephone line into a digital signal that is compatible with an interface in the local PC. This device may either be provided by the local service provider or purchased locally at stores such as BestBuy. It is not unusual for the router to have additional features such as multiple ports or a basic firewall function.

Technical Direction

Implementing Digital Subscriber Line services is becoming routine as the telephone company employees become better trained with skills beyond simple dial tone and voice quality. New equipment approaches are being developed as the telephone companies develop product offerings that include DSL data services.

Some of the technical advances in equipment include:

- Remote DSL concentrators, or loop extender systems, that are rugged enough to be placed in external environments close to the user community. This helps to reach the customer communities that are more distant from the central office.
- Hybrid systems that use fiber optics from the central office to a nearby user community and existing copper to a cluster of homes. This approach holds the promise of high bandwidth capabilities that can support that can support product offerings such as video on demand and data services with speeds between the current T1, 1.5 Mbps, and T3, 45 Mbps, to more closely match consumer needs [2].
- Variations of the existing DSL standards are being designed that use modulation schemes that extend the reach of DSL technology beyond 18,000 feet from the central office [3]. This allows more homes and businesses to be reached using the existing copper cable plant.
- Some carriers are moving the DSL Access Multiplexer out of the central office to remote locations to reduce the length of the copper to the subscriber location [4]. A high-speed datalink is run from the central office to the remote terminal location over a fiber optic-based network moving the digital section of the network beyond the central office. This configuration is called a fiber-to-the-curb (FTTC) approach.

Many of the problems encountered bringing high-speed DSL service to a subscriber community are no longer technical. As the telephone companies have been slowly moving forward to implement DSL, the cable television companies have been very aggressive developing standardized, low cost cable modem technology [5]. The cable companies have captured 70 percent of the residential subscribers that want high-speed access, currently about 15 percent of the total residential market.

The telephone companies are encountering other problems. DSL is more expensive to install than a cable modem [5]. Falling demand for other business and residential services, such as multiple lines, is reducing the capacity of the telephone companies to make investments in infrastructure. DSL devices are estimated to cost almost $200 more than an equivalent cable modem-based link [5]. The residential consumer is very cost sensitive making it more difficult for the telephone company to compete with the cable company. In the business market many of these competitive pressures are less severe. The cable companies are only beginning to provide business services and many of the companies are less sensitive to price than the residential customer [6].

Return to Appendices

In summary, DSL technology is a workable technology that is reliable. Many of the problems with obtaining a DSL link have more to do with telephone company finances and local laws or politics than with the technology. However, many of the telephone companies are seeking to expand their product base by bundling video services from satellite providers [7]. Should these companies begin to migrate video on to their cable plants non-copper technologies will be needed to support these services.

Technology Implementation

Equipment cost	$700
Monthly cost, video	unknown
Monthly cost, HS data	$60-$175
Link distance	0-5 Km
Line of sight required	no
Individual link speeds	1.5 Mbps to 22 Mbps depending on distance
Implementation time	weeks
Support effort	low
Support frequency	as needed
SNMP-based monitoring	yes
Video support	limited
IP telephony support	yes
Internet access support	yes
Support most LAN protocols	no, IP only

Usage Analysis

Short distance p-p	yes
Long distance p-p	no
Short distance multipoint	no
Long distance multipoint	no
Mesh configurations	yes

Interesting Websites

The vendor and organization Websites are shown in alphabetical order may provide additional information:

www.alcatel.com
www.adtran.com/
www.cedmagazine.com
www.commweb.com
www.redback.com
www.tmcnet.com
isp.webopedia.com
www.xchangemag.com

Return to Appendices

Figures

1. DSLAM access controller. www.adtran.com

2. Drawing inspired by installation instructions shipped with DSL equipment by Ameritech.

References

[1] DSL Spectrum Management Standard. IEEE Communications Magazine, November 2002, pages 116 through 123. The author is Kenneth J. Kerpez.

[2] An article by the Telecom Agents Group titled “Very Short Reach DSL?”. http://www.soundingboardmag.com/articles/151feat1.html

[3] An article by BroadbandWeek.com titled “Topping DSL’s Distance Barrier.” Broadband Week April 16, 2001. http://www.broadbandweek.com/news/010416_news_range.htm

[4] An article by CNN.com titled “DSL vendors look to extend service reach.” CNN.com April 4, 2000. http://www.cnn.com/2000/tech/computing/04/04/extend.dsl.idg/

[5] How Phone Firms Lost to Cable In Consumer Broadband Battle, The Wall Street Journal. The authors are Shawn Young and Peter Grant. Online edition March 13, 2003. www.wsj.com

[6] Enabling Value-Added Service Creation. Internet Telephony Magazine, November 2002. http://www.tmcnet.com/it/1102/1102eff.htm

[7] Filling Up on Fiber by Jeff Baumgartner. CED Magazine, March 2004, pages 18 through 22.

Return to Appendices

Introduction to Cable Television (CATV) Infrastructure

Abstract:

CATV technology depends upon the infrastructure (cable plant) to distribute programming and services from the headend to the subscriber population. This paper will present the basic technology used to distribute CATV programming and services then introduce some of the challenges presented by data and telephony technologies.

Basic CATV Cable Plant Components

The CATV system is composed of several key large elements:

- Headend – The origination point of the cable system. All programming is distributed throughout the system starting from this point.
- Cable Plant – Provides the distribution of the programming to the subscribers.
- Subscribers – The paying customer.

The cable plant provides the capability to distribute programming, data, telephony and other products over an area the size of a small of medium size city. Large cities are covered by using multiple, distributed hub locations. The ability of the cable plant to deliver the companies' products over a large area in a quality and reliable manner is key to the economic survival of most cable companies. The majority of systems are analog-based broadband, or wideband, systems that support forward (to the subscriber) distribution and increasingly reverse (from the subscriber) distribution of content.

This two-way capability is provided through the use of filters placed in the amplifiers that divide path direction based upon frequency bands. A common frequency allocation is 5 MHz to 42 MHz for the reverse path and 54 MHz to 450 MHz for the forward path. This provides about six reverse channels and 70 forward analog channels on the typical system. More recent systems have been able to extend the forward frequencies to 750 MHz by changing the characteristics of the forward amplifiers and altering the physical layout of the system.

The frequency allocation [1] of the CATV system is based upon 6 MHz channels that have their historical significance based in the original 13 channel frequencies assigned with the invention of the broadcast television. The same 6 MHz channel allocation standard has been maintained while the upper usable limit for the cable plant has increased from 300 MHz to 1,000 MHz. This 6 MHz channel is only required when television-oriented programming is being transmitted. The cable plant is wideband in nature with the only upper and lower limits of the forward and reverse paths being fixed by the characteristics of the amplifiers.

Consider the sending and receiving devices require identical characteristics to operate correctly. For example, a television signal uses 4.5 MHz of the 6 MHz channel for meaningful information with 1.5 MHz of guardband [1]. Compare this to data that uses the entire 6 MHz channel for the transfer of meaningful information. This demonstrates the need for the coordinated layout of frequencies broadcast on the cable plant to reach the desired economic result for the overall CATV system.

This document will only cover the distribution, or cable plant, portion of the of the CATV system.

Return to Appendices

Traditional Coaxial Cable Plant

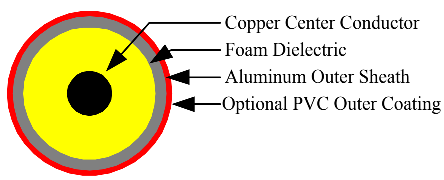
The traditional coaxial cable plant is constructed of the following five common components:

1. Coaxial cable
2. Amplifiers (actives)
3. Splitters and directional couplers (passives)
4. Taps (passives)
5. Power supplies

Each of these components is used to create a cable plant that runs from a common source, the headend, to many destinations, the subscribers. The cable plant accomplishes this using a trunk and tree topology with the trunk starting at the headend and extending out like a tree to pass the greatest number of possible subscriber locations (homes passed).

Coaxial Cable

Figure 1 illustrates the most common configuration for a coaxial cable.



Coaxial Cable Construction
Figure 1

The cable provides two functions, transportation for Radio Frequency (RF) signaling and distribution of Alternating Current (AC) power to operate the amplifiers. Each of the four parts of the cable performs a specific function in the successful transmission through the cable.

The copper center conductor acts as the main path of the high frequency RF signaling. It also acts as one half of the path for the 60 to 90 volts AC that is used to operate the amplifiers.

The foam dielectric serves as the insulator between the center conductor and the aluminum outer sheath. It plays a key role in maintaining uniform characteristics within the cable by maintaining the distance between the inner and outer conductors.

The outer sheath provides shielding from outside RF interference sources, prevents the RF on the cable from leaking to the outside world, and provides one path for power distribution on the cable. This sheath also provides for physical integrity of the cable that allows it to be strung between poles or run underground.

An optional outer coating is used many times to provide additional protection for the cable. A PVC coating is most commonly used to prevent corrosion and improve abrasion resistance. Additional coatings may be placed on the cable during the construction process where problem areas exist. A common product is tree guard that prevents the movement of the cable against a tree from wearing through the outer sheath. Tree guard also provides a customer relations tool as many people object to removing part or all of a tree so a CATV cable can be run through the easement section of their property.

Coaxial cable comes in a variety of configurations to meet the specific requirements of a particular part of the cable plant. Cable used in CATV systems has one common characteristic; the impedance is always 75 ohms.

Amplifiers

Amplifiers are placed in the cable plant to add power and correct distortions induced by the characteristics of the coaxial cable. Amplifiers have some of the following characteristics:

- Establishes the frequency split in two way systems.
- Adds gain to compensate for cable loss
- Provides equalization
- Amplifies noise as well as the desired signals.

Figure 2 provides a view of an amplifier installed in an overhead cable plant.

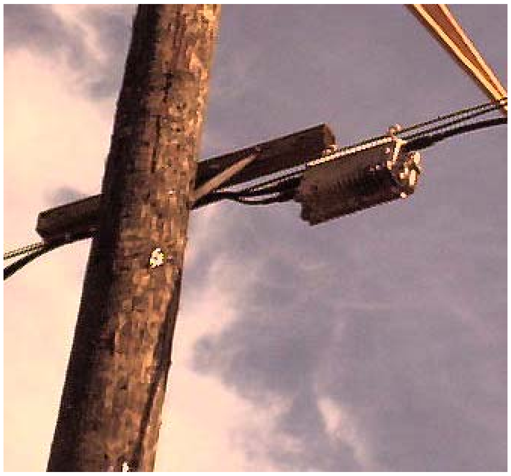


Figure 2 CATV Amplifier

The particular amplifier in Figure 2 appears to be a trunk amplifier with one input, one output and a third link supplying a signal to a local distribution cable for the adjacent homes. This is an internal combination that also be accomplished externally with a directional coupler and a distribution amplifier.

An amplifier is inserted into the line to offset the loss of signal caused by the characteristics of the coaxial cable. A typical 0.500-inch hard line coax cable will have a loss of about 1.70 dB per 100 foot of cable at 500 MHz [15]. This means that an amplifier will need to be inserted into the cable for every 1,300 feet of cable to compensate for loss. Usually this space is less as passive devices such as splitters and directional couplers are inserted in the cable between the amplifiers to allow for legs to attach to the trunk.

Return to Appendices

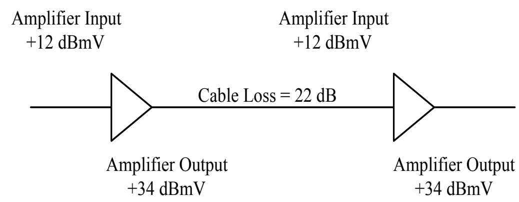


Figure 3 Cableplant Loss Example

Figure 3 shows a loss example for a CATV cable plant. This example assumes each amplifier needs an input of +12 dBmV and provides and output of +34 dBmV. If the cable has a loss of 22 dB, the equivalent of about 13,000 feet of 0.500-inch cable, the signal level +12 dBmV required to drive the next amplifier will be available. This type of calculation is performed as part of the cable plant design process that determines the placement of amplifiers within the cable plant.

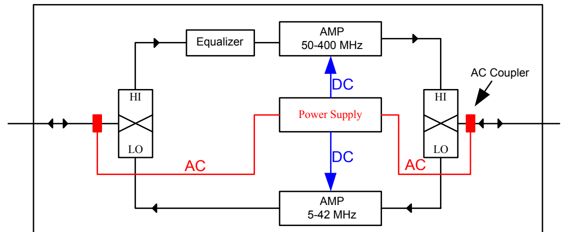


Figure 4 Basic Two-way Amplifier

Figure 4 shows the typical block diagram of a modern analog amplifier. The components in the amplifier shown are:

- Hi/Lo Diplex Filter – Establishes the frequency split for the system. These must be uniform for all amplifiers in the cable plant.
- Reverse amp. – In a commercial CATV system this is always the 5-42 MHz frequency range where traffic moves from the subscriber back towards the CATV headend.
- Forward amp. – In a commercial CATV system this is always the 54 to 450+ MHz frequency range where the traffic or programming moves from the CATV headend to the subscriber. Many of the newest amplifiers have the capacity to operate to frequencies exceeding 750+ MHz.
- Equalizer – In a typical 0.500-inch hard line coax cable [15] there is a significant difference in cable loss between the frequencies of 54 MHz and 450 MHz. The equalizer is used to remove this tilt from the system so all frequencies are amplified equally.
- AC Coupler – Passes the AC voltage on the cable from input to output to provide power on the cable for subsequent active devices.
- Power Supply – Takes the 60 to 90 volts AC on the cable and generates the internal DC voltages used by the active components within the amplifier.

Modern amplifiers have several additional components such as status monitoring, bridger or distribution ports, backup amplifiers and backup power supplies. These are used to make the system more reliable and simpler to maintain.

Return to Appendices

Passives

Passive cable plant components include directional couplers, splitters and taps. Devices are called passives as they consume no AC power and result in some signal loss when used. Splitters and directional couplers serve a similar purpose. They divide the output of a single cable between two or more cables. The splitting of the cable results in less power being distributed to each of the new legs in the cable plant.

In the case of the splitter, power is split equally between all legs. For example, a two-way splitter will have one input port and two output ports with a loss from the input to the output of 3.5 dB.

Figure 5 Typical hardline passives

The directional coupler is similar. For example, a two-way directional coupler will have a through leg and a down leg. This results in one input port, a through leg output port with about a 1 dB loss and a downleg port with 8, 12, 16 or 20 dB of loss depending upon the model. The directional coupler is most commonly used when a local distribution leg is split off of a main trunk run. It is expected that a distribution amp will be inserted near the directional coupler.

Figure 6 Directional Coupler

The subscriber tap is the most common passive found close to the home. It provides a connection for numerous drop cables for links to adjacent homes. The tap has a changeable faceplate with various levels of attenuation so the correct signal level can be delivered to the home television. Tap values run from a four to 32 dB loss. The particular value of the tap depends upon the homes relative position on the trunk cable and the nearby amplifier.

Power Supplies

Power supplies are used to convert the 100 20 volts AC received from the power company to the 60 to 90 volts AC, depending upon the design of the system, that is required on the coaxial cable to power the active components. During the design process various locations are identified where each power supply must be inserted into the system.

Return to Appendices

The requirements include a specific number of powered components (amplifiers), a pole capable of supporting the weight of the supply and the ready availability of AC power. A power inserter is placed on the cable to feed power into the network. Periodically, power isolators are inserted into points in the cable plant to prevent the interaction of power supplies. The power isolator prevents the flow of low frequency (60 cycle) power while not presenting any impairment to the desirable high frequency-based information.

Figure 8 - Typical CATV Power Supply

Some power supplies have additional capabilities such as remote status reporting modules that send information on output voltage and load, temperature or other key variables that may provide predictive details on the supply operation to the operator. Another feature that has small following is an inverter and batteries to provide some continuation of service for short losses of commercial AC power.

Cable Plant Topology

The typical topology for the traditional cable plant is a trunk and tree configuration. The center or base of the main trunk is the cable companies' headend facility and the ends of the tree being the rows of subscriber homes.

Figure 7 illustrates the typical topology of the traditional cable plant. The cable plant is composed of amplifiers placed at regular intervals on the coax plant. Directional couplers or splitters are used to divide the cable plant into a series of legs that spread out to support the potential subscriber population (homes passed). Subscribers are connected to the cable plant using taps placed on the cable at regular intervals.

Return to Appendices

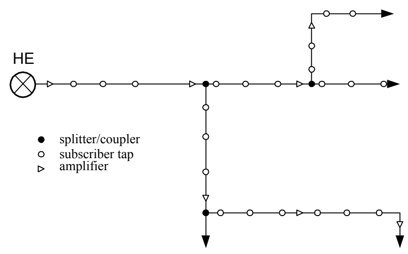


Figure 7 Typical Cableplant Topology

The figure shows the placement of components in a system with a more rural customer base where subscriber connections are widely spaced. A more common trunk and feeder approach is used in the city and urban environments. Here the subscriber taps are restricted to the feeder legs with the trunk providing only signal transportation between the headend and each of the feeder trunks.

Building a large cable plant is a design effort that must blend the coverage of an area with overall cable plant distortions [4]. In general, the size of a cable plant is limited by the accumulated distortions caused by the cascading of amplifiers. Various topologies have been used to overcome these distortion problems. One approach is the trunk and feeder systems where each segment of the system is engineered to perform its function in an optimal manner. There exists substantial knowledge on the best methods needed to build both trunk and feeder systems. Design programs, such as LoadCAD, exist to provide the designer of CATV systems tools to design large systems.

In the past five years most of the effort to build large analog CATV cable plants has made a dramatic shift with the introduction of fiber optic technology. The job of providing a trunk system has moved to a series of point-to-point fiber optic runs that connect each feeder system directly to the headend. This Hybrid Fiber Coax (HFC) technology will be discussed later in this paper.

Cable Plant Distortions [5,6]

Cable plant distortions limit the size of the traditional CATV cable plant. As amplifiers are placed in cascade, one after another, the effects of noise being amplified along with intelligent information becomes significant. Two types of distortions limit the cable plant:

1. Noise
2. Intermodulation

Noise [5] is produced within an amplifier due to random electron movement within the conducting material of the device. This noise is added to the signal being amplified between the input and the output of the amplifier. The measurement of this noise is called the carrier-to-noise ratio (C/N). The theoretically perfect amplifier is calculated to have a carrier-to-noise ratio of –59 dBmV. A typical low priced amplifier, the Viewsonics VSMA-10-1000, has a C/N ratio that is 6.5 dB lower than perfect at 52.5 dBmV.

Return to Appendices

As amplifiers are used to increase the power (gain) of the signal that is lost due to the characteristics of the cable, noise is also amplified. As each amplifier adds its noise the effect becomes cumulative until it interferes with the intelligent information. In a CATV system the noise becomes a problem when it becomes visible to the subscriber. Cable companies have standards for acceptable C/N ratio with 43 dB being common [5]. Increasing the C/N ratio above 43 dB does not have a significant effect on the picture quality, but does increase the cost to build the cable plant. The carrier-to-noise ratio of the system is established as part of the design process and confirmed during the performance testing process at the completion of the system build.

The cable plant must be periodically re-tested to confirm that the distortion characteristics of the system have not deviated from the original design criteria. Properly maintained systems are certified once or twice each year to meet the design specifications.

Evolution of the Coax Cable Plant

The traditional coaxial cable plant has successfully delivered 30 to 60 channels to television to the majority of homes in the United States. As the traditional cable plant became larger and more complex so did the process of finding and eliminating distortion problems. A cable plant with 35 amplifier cascades, the size of a medium city, becomes very labor intensive, and expensive, to maintain successfully. As new demands for expanded bandwidth and higher reliability are required, the coaxial-based system is not up to the challenge.

The modern Hybrid Fiber Coax system was design to eliminate many of the problems found with coaxial-based systems. This was accomplished by eliminating long runs with many trunk amplifiers with long runs of fiber optic cable with very few amplifiers. This presents an economical approach to building many smaller cable plants as opposed to one very large cable plant.

Hybrid Fiber Coax Systems

The Hybrid Fiber Coax (HFC) system modifies the traditional coax cable plant by replacing the long runs of cascaded trunk amplifiers with long point-to-point links over a fiber optic cable. The HFC system is composed of three components:

1. A fiber transmitter
2. A single mode fiber optic cable
3. A fiber receiver

The Basic HFC System

The fiber optic transmitter takes an analog 50 MHz to 750 MHz coaxial input and uses this signal to heterodyne with a laser-based carrier that is placed on the fiber cable.

A run of single mode fiber is the transport mechanism. This replaces the coaxial cable and cascaded trunk amplifiers that were used in older systems. This transport is capable of delivering high quality signaling at distances of 20 miles. This occurs without the need for intermediate amplifiers or power supplies in the fiber optic cable run.

Return to Appendices

At the remote location, a fiber optic receiver converts the optical signal back to a coaxial-based analog signal for local distribution.

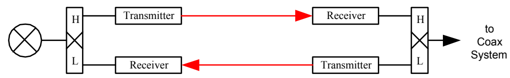


Figure 9 - Typical HFC Configuration

Figure 9 shows a block diagram of the fiber optic portion of an HFC system. The coaxial-based feed is taken from the headend, placed on a fiber optic transport to the remote node location and then placed back on a local coaxial-based feed to the first coax-based feeder amplifier.

HFC System Impact

The advantages of this approach include:

- Improved overall distortion characteristics over long distances.
- Lower cost of ownership as the transport has much lower maintenance requirements when compared to a traditional coaxial-based distribution system.
- The fiber is not affected by external radiated emissions, magnetic fields, leakage, etc.
- As the forward and reverse paths are on separate independent fibers it is possible to build different bandwidth allocations. For example, forward with a 50-750 MHz bandwidth and the reverse with a 5-200 MHz bandwidth.
- The capability to use Wave Duplex Modulation (WDM) to place multiple signals on one common fiber optic link.
- Allows the consolidation of multiple headend locations within a city to one or two super-headends.


Figure 10 HFC Components

As Figure 10 shows, the HFC amplifiers have the same form factor as the older analog amplifiers placed in the cable plant. A fiber optic cable connects to one end of the amplifier and a coaxial cable connects to the other end of the amplifier. A similar set of components is rack mounted at the headend to provide the link between the headend and the fiber link. This is the transceiver that converts the coaxial-based signaling used in the headend to a fiber optic-based signal to the first HFC amplifier many miles distant.

Return to Appendices

No technology is perfect. The HFC amplifier does have some adverse impact on the cable company. With an HFC link serving a small number of homes passed, typically 100 to 500, the equipment space required in the headend expands dramatically. Many cable companies have recognized this space requirement and combined this need with that of new products, such as Internet services, and built new buildings.

Implementing the HFC technology is a costly capital expenditure as the cable plant becomes very fiber optic intensive. Along with the installation of the fiber optic components comes the need for extensive retraining of the cable companies' employees and upgrade of test equipment to maintain this new technology. Offsetting factors favor the HFC systems configuration for the long-term including the need for fewer employees because of significantly better system reliability and performance leads, a lower operating cost for the system along with better subscriber satisfaction.

Not all problems are solved by HFC. The basic cable plant in the United States is still a subsplit (5-42 MHz/54-750 MHz) configuration that limits the return path bandwidth. This return path is in demand for the new two-way products such as telephone and Internet services.

New Product Impact on the Cable plant

The introduction of new products, such as high-speed Internet service and telephony has significant impact on the state of the cable plant. These services present certain problems to the cable company including:

1. Lifeline telephony service requires always on service even if commercial power is not available.
2. Additional reverse channel bandwidth is required as the customer base continues to grow.
3. High-speed Internet services on the return path are sensitive to interference that is most noticeable [12] in the 5 MHz to 30 MHz band.
4. The implementation of the return path and associated services on the cable plant requires new types of training, test equipment and skills for the employees [12].
5. The customer service expectations [8] for these new services are significantly different when compared to one-way television products.

New Approaches to Power [8]

The cable company can no longer be totally dependent upon the commercial power company to maintain cable plant operability. New products, such as lifeline telephone (the primary telephone in the home) require operability even in the absence of commercial power. The cable companies are beginning to install power supplies with built in backup batteries.

Return to Appendices

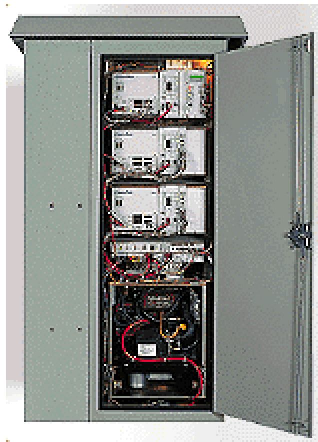


Figure 11 CATV Power Supplies with Natural Gas Generator backup

Figure 11 shows one example of a CATV cable plant power system combined with a generator backup to maintain continuous power for active cable plant components. These power units will be installed at key locations throughout the cable plant. Should commercial power cease, the power supply will operate briefly on battery until the generator begins to supply power. For a natural gas powered unit the generator can run as long as natural gas is available. In most cases, the reliability of the natural gas system seems to exceed that of the commercial power company.

The Return Path Problem

The small number of channels available in the return path, from the customer to the headend, is a major limitation [11] of the cable plant. Significant effort has been made to reduce this problem including:

1. Decrease the number of homes support by each fiber optic link (reduce the number of homes passed).
2. Use stacking to place multiple returns on a single fiber [9].
3. Use a digitized return path [11] and DWDM [10] technology to place multiple returns on a single fiber.

Decreasing the number of homes passed is the basic approach of the modern HFC-based cable plant. This reduces the number of customers supported by a single cable, therefore, reduces the demands upon the return path while yielding an improved quality signal [12] because of the reduction of active components.

Return to Appendices

What happens when the demand for reverse bandwidth exceeds the six available channels? Some companies [9] use an approach that reduces the number of homes passed for just the area with the reverse channels are congested. They are using existing coax to reduce the number of homes served by a particular reverse. This provides an asymmetrical relationship between the forward and the reverse. The forward passes more homes and the reverse passes fewer homes. They bring three reverse only feeds to a special fiber optic node that has a bandwidth of 5 to 200 MHz. This node is capable of stacking three reverse groups on the fiber using a multiplex approach, block conversion [11, 14]. When this signal arrives at the headend it is converted back to the normal reverse frequencies for normal processing of the information. Some people are advocating the combination of analog block conversion with the process of DWDM to allow a single return fiber to carry up to 144 return bands [14].

Scientific Atlanta and General Instrument (Motorola) [11] are using a different approach to this problem using a baseband digital reverse rather than block conversion. Much like the previous approach, the reverse and forward populations are split asymmetrically. Rather than using an analog approach, block conversion, to multiplexing the three reverse groups back to the headend, they are using a digital approach. This approach digitizes the entire reverse analog bandwidth into a high bandwidth, digital signal. Multiple signals are brought to a common point and placed on a single fiber using DWDM multiplexing. It addition to providing a cleaner signal the technology allows longer distances between the fiber node and the headend.

Technical Direction

Fiber optic technology continues to push further into the CATV cable plant with the latest technology supplying fiber-to-the-home (FTTH), also known as fiber-to-the-premises (FTTP), and fiber-to-the-business (FTTB). Many companies and cities are evaluating all approaches for building a new CATV system and finding that the all fiber approach has a similar cost to the HFC configuration. This is particularly true in the buildout of greenspace, or open, areas where all new cable must be installed.

New products are being developed that allow hybrid connections between the user community and the CATV cable plant. For example, a strand mounted wireless unit [16] combines a cable modem with a high-speed Ethernet wireless transceiver to provide a data link to a nearby user without the need to run additional cable. This approach allows the cable company to provide additional services without additional infrastructure or back office changes.

Conclusion

The cable companies are seeing a significant revenue opportunity through enhanced services such as high-speed Internet access, Video-on-demand, and telephony services. The existing copper-based cable plant is a significant barrier to successfully providing these services.

In response to these problems the cable industry is in the process of upgrading to HFC technology. It is anticipated that by the year 2003 about 80 percent [13] of the cable plants in the United States will be upgraded to this new technology and capable of supporting the enhanced services.

As they enhanced services are implemented strategies to provide reliable service and adequate bandwidth will be put to the test. Predictions for these services are about 20 percent of customers will have high-speed Internet and 30 percent will have telephony service [13]. For these estimates to be reached, increases in cable plant reliability are needed.

Return to Appendices

Technology Implementation

Equipment cost	substantial
Monthly cost, video	$30-$80
Monthly cost, HS data	$40-$60
Link distance	2-40 Km
Line of sight required	no
Individual link speeds	analog
Implementation time	years
Support effort	substantial
Support frequency	regular
SNMP-based monitoring	yes
Video support	yes
IP telephony support	evolving
Internet access support	yes
Support most LAN protocols	no, IP only

Usage Analysis

Short distance p-p	yes
Long distance p-p	yes
Short distance multipoint	yes
Long distance multipoint	no
Mesh configurations	no

Interesting Websites

The vendor and organization Websites are shown in alphabetical order may provide additional information:

www.alpha-us.com
www.c-cor.com
www.cedmagazine.com
www.lindsayelec.com
www.motorola.com
www.sciatl.com
http://wireless-bypass.com

Return to Appendices

Figures

1. Coaxial Cable Construction. Original drawing by Roger Swenson.
2. CATV Amplifier. Picture taken of cable plant belonging to Garden Isle Cable in Lihue, Hawaii by Roger Swenson.
3. CATV cable plant loss example. Copied from Cable Television, Third Edition. William Grant, copyright 1988 and amended in 1994, Figure 2-1 on page 27. Drawn by Roger Swenson.
4. Basic two-way amplifier. Drawn by Roger Swenson. Based upon drawings from Cable Television, Third Edition. William Grant, copyright 1988 and amended in 1994, figures 3-1 and 3-2 on page 38.
5. Typical hardline passives. http://www.lindsayelec.com/hardline.html
6. CATV passive. Picture taken of cable plant belonging to Garden Isle Cable in Lihue, Hawaii by Roger Swenson
7. Illustration drawn by Roger Swenson. Similar to Cable Television, Third Edition. William Grant, copyright 1988 and amended in 1994, figures 15-1 on page 214.
8. CATV power supply. Picture taken of cable plant belonging to Oceanic Cable in Honolulu Hawaii by Roger Swenson.
9. Figure 9. Illustration drawn by Roger Swenson.
10. Figure 10. Typical HFC amplifier and headend transceiver, http://www.c-cor.com/main.htm.
11. Figure 11. Integrated CATV power supply with natural gas generator backup. http://www.alpha-us.com/product/broad/integrated/bpsse.html

References

[1] Cable Television, Third Edition. William Grant, copyright 1988 and amended in 1994. Chapter 1, Coaxial Cable Transmission Systems, page 6, Transmission Spectrum Allocation.

[2] Cable Television, Third Edition. William Grant, copyright 1988 and amended in 1994. Chapter 8, Coaxial Cable and Reflections, page 109, Table 8-A

[3] Cable Television, Third Edition. William Grant, copyright 1988 and amended in 1994. Glossary, pages 487 through 516

[4] Cable Television, Third Edition. William Grant, copyright 1988 and amended in 1994. Chapter 14, Urban System Design, pages 197 through 206.

[5] Cable Television, Third Edition. William Grant, copyright 1988 and amended in 1994. Chapter 4, Noise, pages 59 through 67.

[6] Cable Television, Third Edition. William Grant, copyright 1988 and amended in 1994. Chapter 5, Intermodulation Distortion, pages 69 through 82.

[7] Cable Television, Third Edition. William Grant, copyright 1988 and amended in 1994. Chapter 28, Hybrid Fiber/Coaxial Systems, page 437

[8] What Happens When, New Services Will Impact Your Plant's Power Structure. Communications Technology magazine, October 1999, pages 86 through 90.

[9] MediaOne Chicago Deploy FAST. Communications Technology magazine, September 1999, pages 61 through 70.

[10] DWDM: 10 Pounds of Light Into a 5-Pound Bag. Communications Technology magazine, September 1999, pages 73 through 84.

[11] Expand Your Return Path Toolkit, Digital Reverse Lowers Costs, Increases Reliability. Communications Technology magazine, October 1999, pages 76 through 84.

[12] Bring It Home, Testing the Return Path. Communications Technology magazine, October 1999, pages 116 through 120.

[13] Mixing IP and HFC, Opportunities, Challenges and the State of the Technology. CED Magazine, August 1999, pages 31 through 40.

[14] The ABCs of Block Conversion, Add RF Capacity Without Rebuilding. Communications Technology magazine, November 1999, pages 64 through 70.

[15] Times Fiber Corporation. Typical specifications for Series 500 coaxial cable. See the Website at http://www.timesfiber.com/pdf/semiflex-attn.pdf

[16] Wireless Bypass, Inc. DL-5800D Doccis compatible wireless link. See the Website http://wireless-bypass.com/products_list.cfm?type=Unlicensed&id=13 for more information.

Return to Appendices

Analysis of Satellite-Based Technology

Abstract:

The need for ubiquitous communications over large geographic areas has created a renewed interest in satellite data communications. New equipment can provide two way high-speed access to the Internet capable of handling a variety of multimedia content. Satellite service continues to evolve from a heritage emphasizing the distribution of television content to incorporate two-way multimedia content and support both fixed and mobile user communities. This document will present an overview of the current state of satellite technology and its future capability to support Internet access. Satellite services are capable of providing Internet service locally, statewide and nationally.

Introduction

Satellite communications has been available for the past 40 years. Many of the first uses of satellite-based communications provided worldwide voice and data links where local land links were not available. The United States government and the telephone companies developed many of the initial satellite-based applications.

The telephone companies used satellite links to provide telephone links between the far corners of the Earth where land-based cabling was expensive or not economically feasible. Links were also used to provide cross county telephone communications as an alternative transport where sufficient land-based resources were not available. Talking over a satellite link was easily identified by the one-half second delay between speaker and listener.

Satellite is well positioned to provide services that originate from one location and are distributed throughout a large geographic area. This is the case with television broadcast programming developed by nationwide networks (CBS, NBC and ABC) and distributed to local stations using a satellite link.

A similar distribution concept came into use with the cable television companies during the 1980s with programming being received from multiple satellite-based sources. The content would be received over a satellite link and inserted into the local channel lineup and then distributed on the cable system providing a combination of local, national, and international content.

The use of satellite communications has changed in recent years. The wealth of fiber optic-based links throughout the United States and between continents has replaced the satellite as the primary transport for long distance voice communications. However, advances in satellite technology such as the use of higher frequencies and high power outputs have presented new opportunities.

One example of new satellite-based services is television broadcast direct to the home where cable services are not available or as an alternative to local cable service. The same dish used for satellite-based television can be modified to provide Internet access [1] by adding additional hardware. One example is the Hughes DiRECWAY™ system that provides Internet service with the capability to support simultaneous television reception from DirecTV.

Return to Appendices

New systems are in the process of being implemented that will be capable to providing high-speed Internet and data services over large geographic areas. This includes services to rural areas not served by existing providers and integrated services for mobile users that work in concert with existing land-based resources [2]. The satellites that are being proposed using a low Earth orbit can be capable of providing voice services that could lead to the development of a hybrid type of cell phone [13]. The technology appears available, yet, the timeframe is uncertain because of the current economic conditions.

Technical Description

The basic satellite system is a two-part functional system composed of the space segment and the ground segment.

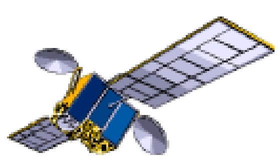
The ground segment is composed of several functional components:

1. A gateway station that provides the link between the space-based segments and the local networks.

2. A network control center that allocates network resources and controls access.

3. An operation and control center that manages the operation of the space-based systems including control of orbits.

In many networks, the ground segment serves as the center of the network. In addition to control functions, the ground segment provides routing of traffic, controls access and manages quality of service. Some of the newer systems coming online in the near future have added additional processing power [3] to the space-based segment to allow the routing of information between numerous ground segments by the satellite.



The space-based systems are classified by orbit characteristics and type of payload functionality. The orbit characteristics address the design of the satellite system such as orbit height and number of satellites. The payload functionality is the amount and type of processing power that is part of the satellite.

Return to Appendices

Orbit Characteristics

The orbit characteristics are divided into three groups:

1. Geostationary Orbit (GSO). The majority of existing satellites have been placed into orbits about 35,000 kilometers above the Earth. This provides an orbit that is synchronized with the rotation of the Earth. This synchronization gives the appearance that the satellite remains over one spot on the Earth.
2. Medium Earth Orbit (MEO). The medium Earth orbit places the satellite about 3,000 kilometers above the Earth. This provides an orbit where each satellite has a line of sight period between a ground station and the satellite of about one hour.
3. Low Earth Orbit (LEO). The low Earth orbit places the satellite between 500 and 2,000 kilometers above the Earth's surface [2]. A satellite in a low Earth orbit will only be visible for 10 to 20 minutes so multiple satellites will need to be used to maintain communications links.

Each orbit provides a tradeoff between the number of satellites, handoff strategy, link latency and total system cost.

For a low Earth orbit system, about 96 [2] satellites are required to provide communications around the Earth. The advantage of this approach is that the low latency of the system (10 to 40 milliseconds) is similar to land-based communications systems making it suitable for real-time communications. A large number of satellites must be used to maintain a continuous communications link so a link handoff procedure must be used as a different satellite will come into view every 10 or 20 minutes.

A medium Earth orbit is a compromise between the number of satellites required, line of sight time between ground station and satellite and link latency characteristics. The medium Earth orbit system requires fewer satellites than the low Earth orbit system, requires a less robust handoff procedure and has higher link latency [2].

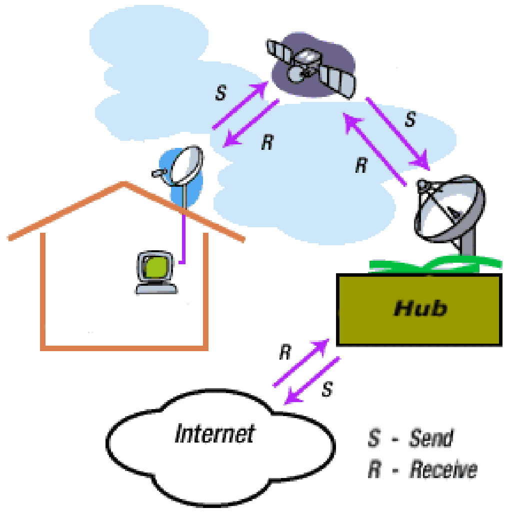
For a geostationary system only three satellites are required to provide communications around the Earth. However, latency, or delay, within the system is about 250 milliseconds making this system suitable for traffic that is not delay sensitive. Examples of this type of traffic include television programming distribution, E-mail and similar types of traffic.

The designer of the satellite system will develop an approach to the satellite system using an orbit the makes the best business case and technical characteristics for the desired application. As an example, a hybrid cell phone system could use a low Earth orbit satellite system to augment coverage in areas where cell towers may not be economical or physically possible to build. This approach could provide cell phone coverage in areas with large bodies of water or low population densities. This is similar to the goals stated for the European UMTS system [2].

Payload Types

The satellite payload take two forms [4], either acting as repeaters or having onboard processing resources. Many of the existing satellites function as a repeater with all of the processing of information performed by the ground segment of the system. Newer satellites are being designed that have the capability to perform onboard routing of data [3] [5] that will allow more efficient use of the communication channel and complex network configuration similar to land-based networks.

Return to Appendices



Referencing the above drawing. The repeater approach has the advantage of being simple and easy to implement. The satellite is smaller, lighter and very reliable. The satellite receives traffic from the ground station, user location, and relays it to the gateway, or hub location, for routing to the Internet. This approach requires that all processing of network layer information be performed by the hub location as it acts as the gateway between the user link through the satellite and the Internet.

In the repeater-based configuration, the ground station, or hub location shown in the drawing, is responsible for channel contention resulting in many overhead messages sent between the remote site and the ground station before the actual data is moved. During the communications process the user location must request a slot from the hub site. With the satellite having no onboard processing this request will be processed by the hub location.

Some of the newer satellites that will become active during the coming years will be in lower or medium Earth orbits and will have onboard processing capability. Systems such as Astrolink, Spaceway™ and Teledesic [4] will have onboard processing that provides processing of network layer data along with the capability to establish intersatellite links. Links between satellites are required for satellites in lower orbits as these satellites must be capable of performing a link handoff function as one satellite moves out of range and the next satellite moves into range of the ground-based user. This approach is similar to the handoff used by the cell phone as the user moves between areas covered by each cell site.

Cost Analysis

Existing satellites are available to provide Internet support to the home and business community. All of these systems are based upon satellites in geostationary orbits. These systems have latency characteristics that make them suitable for data links that do not require realtime communications, no IP-based telephony type of traffic. Some examples of full two-way services include:

1. DiRECTWAY [6]. Two-way service offered through the reseller community. Installation costs $99 with monthly fees at $99 per month for the first year and $59 per month in subsequent years. Speed is claimed to be approximately seven times faster than dial-up services. DiRECTWAY currently has over 160,000 subscribers in the United States [15]

Return to Appendices

2. Clarity Connect [7]. A private branded satellite service. Initial equipment costs are $299, installation is between $100 and $150, monthly charges are $54.95 when billed yearly. Speed is describes at up to 400 Kbps.

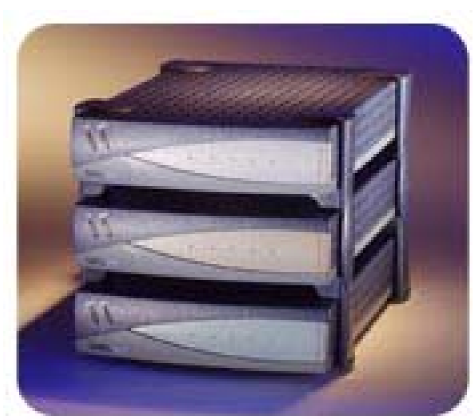
3. StarBand [8]. Starband offers two-way satellite services using the resources of Gilat Satellite. The equipment cost is $499 with first year service at $69.99 per month and subsequent years service at $59.99 per month. Business-oriented services are also available. The speed of the service is quoted as 10 times that of a dial-up link.

4. Aplus.net [9]. Aplus offers a T1 replacement service for rural areas. Depending upon the throughput required, rates run from approximately $280 per month to $1900 per month.

Typical Equipment

The equipment used by most vendors is similar in size and shape to the Hughes DiRECTWAY™ [11] dish.

A two-way system will have two coax cables running from the dish into a local interface unit in the home or business. The entry-level units will have a USB interface that will support one PC as the target market is the home user.



The business user would need a unit with an Ethernet interface that is capable of supporting Internet access by multiple PCs in a LAN environment. The Hughes DW4020™ [12] pictured above is one example of this type of device. This type of system is capable of T1 like performance although the throughput may vary based the monthly fee that is selected by the user.

Return to Appendices

One-way systems are still available. These use the satellite link to provide a high-speed receive path and a dial-up modem link for the transmit path. These are a lower cost on demand type of system marketed to the occasional user that does not require an always-on Internet connection.

This equipment represents the currently available technology. Newer services coming online during the next two years may take a different approach for the user premises devices.

Technical Direction

Four satellite networks are proposed to begin providing service between 2002 and 2004. The four networks [4] are Astrolink, Skybridge, Spaceway and Teledesic. Two systems, Astrolink and Spaceway, will be geostationary systems with between four to nine satellites. Skybridge and Teledesic will be low Earth orbit systems with between 80 to 288 satellites.

All of these satellite systems are targeted to provide high-speed data-oriented services. Each of the systems has a variety of configurations [4], Skybridge is a bent-pipe system, the others have onboard processing and are capable of intersatellite links. Each system is implementing a variety of performance enhancements to support the use of TCP/IP through a satellite link without the degradations caused by latency and data errors. Latency is one of the limiting factors in the services that can be supported by satellite links. When an Internet link is supported by a satellite "voice over Internet and real-time online gaming do not work well" [10].

A recent article [10] points out that there is a significant opportunity for satellite services. A survey finds that there are 30 to 40 million homes and seven million small businesses in the Unites States that do not have high- speed DSL or cable modem services available over terrestrial networks. This is the prime market for satellite services. As pointed out by a recent article [13], "satellite links, as an integral part of the global communications infrastructure, are already used to provide IP-based data services, especially to remote regions in developing countries where terrestrial communications infrastructure is scarce or even nonexistent, and as backups for terrestrial links in more developed areas." I suggest that this description could be extended to many areas of the United States where satellite communications can be expected to provide high-speed, always on links to the Internet as a replacement for the dial-in connection.

Advantages and Disadvantages

The existing satellite systems such as those provided by StarBand and DiRECWAY are adequate to meet the requirements of the user community in rural or underserved areas that require Internet access. Many of these systems are reasonably priced and quick to install. It is possible to startup a satellite link in just a few hours.

Recognize that these systems have limitations including:

1. High latency that limits use to data only, none real-time applications. This means support for IP Telephony, net-based video-oriented conferences and similar applications cannot be supported.
2. Lower priced one-way systems are available for the user that will accept the use of the existing telephone line as part of the link.
3. Two-way systems are available providing always-on and performance characteristics similar to a cable modem.

Return to Appendices

4. Two-way systems are available to provide always-on and performance characteristics similar to a T1 line for the business user. These types of links generally have a higher price than those that are marketed to the home user. These systems can be configured to provide symmetrical service, same transmit and receive speed, that required by a business user.
5. Satellite service is subject to periodic weather related outages including the angle of the sun twice each year behind the satellite and interference caused by heavy rain.

Companies to Watch

Four companies should be watched in the near future as they have plans that will add significant capacity and features in the satellite market [4]. In most cases these companies are in a go-slow mode based upon the current economic conditions [14]. The companies are:

1. Astrolink. Astrolink was sponsored by Lockheed Martin. They are looking for financing to launch the first two satellites over the Americas and Europe.
2. Skybridge. Skybridge is a company owned by Alcatel, Boeing, Gilat and others. It currently provides service using an existing geostationary satellite (StarBand is a marketing group for this service in the United States). The proposal to launch 80 satellites in a low Earth orbit has halted because of low demand. Geostationary satellites are more likely. Skybridge has teamed with Gilat to form SATLYNX. Alcatel has recently purchased Europes *Star satellite system.
3. Spaceway. Spaceway is still being promoted by Hughes Network Services. Hughes will launch the first North American satellite in 2003 [15] with service beginning the following year. Spaceway currently advertises the start of commercial services during 2004.
4. Teledesic. Teledesic has moved from placing 288 satellites in a low Earth orbit to 30 satellites in a medium Earth orbit to lower the price of the system. The company still advertises that it will begin commercial services during 2005.

The key indicators for satellite becoming a robust business are when the two current providers, StarBand and DirecWay, begin to become profitable. Both companies have had mixed success in the residential market and are refocusing on a broader market that includes the business community [14].

Technology Implementation

Equipment cost	$500
Monthly cost	$60
Link distance	0.1-6Km
Line of sight required	yes
Link speeds	400 Kbps
Implementation time	one day
Support effort	high
Support frequency	infrequent
SNMP-based monitoring	yes
Video support	yes
IP telephony support	no
Internet access support	yes
Support most LAN protocols	no

Return to Appendices

Usage Analysis

Short distance p-p	no
Long distance p-p	no
Short distance multipoint	yes
Long distance multipoint	yes
Mesh configurations	no

Interesting Websites

The vendor and organization Websites are shown in alphabetical order may provide additional information:

www.aplus.net
www.astrolink.com
www.clarityconnect.com
www.direcway.com
www.gilat.com
www.hns.com
www.nationwidesatellite.com
www.skybridgesatellite.com
www.starband.com
www.teledesic.com

References

DiRECTWAY and related products is a trademark of Hughes Network Systems.

SPACEWAY and related products is a trademark of Hughes Network Systems.

[1] http://www.hughes.com/consumer/direcway.xml describes the support for one-way and two-way Internet services along with television-based content from DirecTV.

[2] Next-Generation Mobile Satellite Networks. IEEE Communications Magazine, September 2002, pages 150 through 159. The authors are Enrico Del Re and Laura Pierucci, University of Florence.

[3] http://www.hns.com/default.asp?CurrentPath=spaceway/benefits.htm. Hughes Network Systems. This article describes the Hughes SPACEWAY system that will provide Internet services to homes and businesses with the launch of satellites beginning in 2003.

[4] Satellite-Based Internet: A Tutorial. IEEE Communications Magazine, March 2001, pages 154 through 162. The authors are Yurong Hu and Victor O. K. Li, The University of Hong Kong.

[5] http://www.astrolink.com/system/kaband_paper.pdf. This white paper describes Astolink's approach to satellite design. Astrolink International LLC, 6701 Democracy Blvd, Suite 1000, Bethesda, MD 20817

[6] http://www.nationwidesatellite.com/highspeed.asp. Reseller for Hughes DIRECTWAY satellite services.

Return to Appendices

[7] http://www.clarityconnect.com/pages.html?page=satellite. Appears to be a DIRECTWAY reseller offering both two way systems and one way telco return systems.

[8] https://signup.starband.com/wheretobuy/index.asp

[9] http://www.aplus.net/services/ia-satellite.html

[10] http://www.isp-planet.com/fixed_wireless/business/2002/satellite_service.html

[11] http://www.direcway.com/default.asp?CurrentPath=direcway/intro.htm is the source of the Directway product information.

[12] http://www.direcway.com/default.asp?CurrentPath=products/direcway_terminals/dw4020/dw4020.htm shows an example of the user premises equipment that would be used by a small business in a satellite environment.

[13] Voice over IP Service and Performance in Satellite Networks. IEEE Communications Magazine, March 2001, pages 164 through 171. The authors are Thuan Nguyen, Ferit Yegenoglu and Agatino Sciuto, COMSAT Laboratories and Ravi Subbarayan, Lockheed Martin Global Communication

[14] http://www.cedmagazine.com/ced/2002/0402/04b.htm reports the current status of plans to launch satellites.

[15] Hughes Network Systems, Inc. Company Backgrounder. Hughes document HSN-25507 dated 1/17/03.

Return to Appendices

Analysis of Power Line Carrier Technology

Abstract:

Power Line Carrier (PLC) has supported automated meter reading and home networking for years and now offers the promise of being able to support high-speed Internet and telephony services. These new services over the existing electricity infrastructure can be offered by power utilities themselves or in partnership with telecom operators. This paper provides a brief overview of the three types of PLC technology. In addition, this paper provides details on Broadband Power Line (BPL), the PLC technology used to deliver high-speed Internet access.

Introduction

There are three types of PLC technology. They are:

1. Home Networking PLC: Provides high-speed data connectivity on a low side of a distribution transformer. Enables a user to create a Local Area Network (LAN) with the existing electrical wiring in a home. Home Networking PLC technologies have become common with the sale of devices at the discount electronics stores to provide an alternative to wireless or UTP cabling throughout the home. Home use of this technology provides high-speed, about 14 Mbps [3], and is easy use, just plug-in to the power receptacle. Encryption is included in the device to prevent disclosure of data to nearby homes that are served by the same power transformer.

2. Distribution Line Carrier (DLC): Provides low-speed data connectivity from the electric substation to the customer premises. Often deployed by electric utilities for support of Automatic Meter Reading (AMR), Demand Side Management (DSM), and Distribution Automation (DA) applications.

3. Broadband Power Line (BPL): Provides high-speed data connectivity over the electrical distribution system that serves households and businesses. Offers the promise of enabling electric utility of offering Internet services over the existing electric distribution system.

The remaining portion of this paper will concentrate on the use of BPL technologies.

BPL technology can be viewed as the ideal approach to high-speed communications. In terms of the first-mile, electrical power connects to nearly every home in the United States. Using this media provides an existing infrastructure that is already in place.

The power utilities hope to build upon their strategic assets including:

- Strong existing customer base
- Existing infrastructure for billing and customer support
- Existing infrastructure for maintenance
- Extensive fiber optic backbone network

The power companies would like to build upon these strengths to provide to expand their service offerings to include high-speed data, telephone and meter reading. PLC technology is a possible conduit for these services.

Return to Appendices

Technical Description

BPL technology used to provide links over the last-mile and as part of a larger distribution system is still relatively uncommon and remains in the testing and development stage. These last-mile systems are currently running in test configurations and still have concerns that need to be addressed. This paper will focus on the power line technology used by the power companies to provide last-mile Internet access.

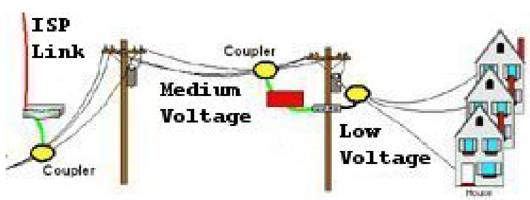
Technology Approach

BPL devices operate in the electrically noisy environment by using high-tech modulation schemes [2] such as ODFM or CDMA. This approach sends out duplicate frames of information at high frequency, between 2 to 30 MHz, over the powerline. Many of the frames will get lost in the noise; those that get through can be reassembled into the original data stream.

This approach comes with some technical [2] problems. The main utility grids transport electricity at voltages between 60,000 and 500,000 so it can travel hundreds of miles to high population areas.

The high voltage lines have been used to transport data, however, many electric utilities have found the economics and performance of running fiber optics parallel to these lines a more effective approach for supporting control and monitoring functions. This fiber usually has excess capacity that could be used for Internet access.

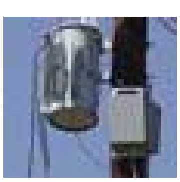
The medium voltage lines, 4,000 volts to 25,000, are more compatible with BPL technology. Coupled with the fiber optics already owned by many power companies, a data distribution system can be created to cover a large number of homes and businesses.



The BPL communication system provides data links between the Internet Service Provider (ISP) and the local user beginning at the medium voltage power lines that feed a neighborhood. Between the ISP and the neighborhood link other media is used such as a telephone lines or fiber optic links.

Five types of devices are used to provide the link to the end consumer in the typical BPL system [1]:

1. Back Haul Interface. This device provides the local interface between the interface that transports data between the BPL network on medium voltage lines and the network used to connect to the ISP. The link to the ISP may be a telephone line or fiber optic link.



2. BPL Coupler. The coupler provides the linking point between the medium voltage distribution line and a local bridge that will distribute PLC-based signaling on the lower voltage lines that run to the homes.

Return to Appendices

3. BPL Bridge. The bridge transports the BPL-based signaling around a transformer. A transformer cannot pass the BPL signaling because of its frequency characteristics.
4. Home Modem. The power line modem is the interface between the subscriber and the power line network. It connects to the customer's PC or other IP-enabled device via a standard computer connection (Ethernet or USB).

5. Repeater. Some vendors have a repeater module that can be used on longer runs. The repeater regenerates the signal.

These technologies are being used to provide high-speed Internet service today. Power companies have these systems in tests in cities such as Allentown and Manassas. Additional tests with cities and power companies are being announced periodically using different vendor’s hardware.

Technical Direction

When the technical problems have been overcome with this technology, the challenge will be to build a business case where the consumer is willing to pay for high-speed service. Recent survey data from the Link Michigan project show consumers are willing to pay about $20 to $30 per month for a high-speed network link. Many business cases show that a price range of $30 to $40 per month from 15 percent of the subscribers passed to be a requirement for building these systems.

A combination of services may be the methodology for building these high-speed networks. Internet access for consumers, remote meter reading, webcams for security, and device control are a range of services that may be required to make a sound business case.

Interference

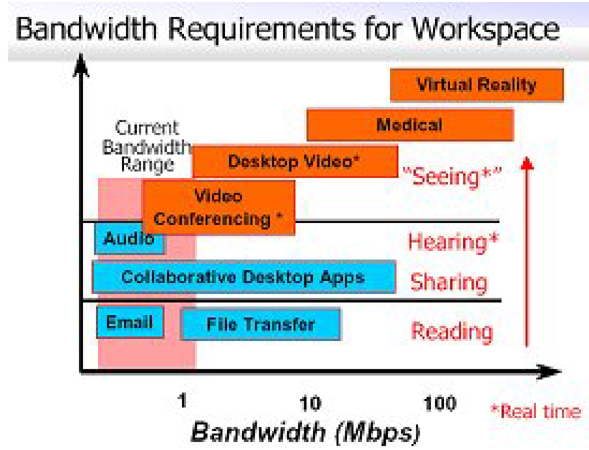
BPL creates or causes electrical interference in the 2 to 32 megahertz frequency range that is used to support this service. Very vocal in the criticism of BPL is the amateur radio enthusiasts that have requested that the FCC ban BPL technology because it is reported to increase the background noise level in the frequency ranges used for ham radio [5]. The FCC has recently opened the debate on this interference by submitting changes to Part 15 of their regulations for comment regarding the effect of BPL technology.

Platform Scalability

Platform scalability refers to the capability of the technology platform to provide adequate bandwidth to support the application requirements to some number of users. The ability of BPL technology to meet the increasing bandwidth needs of a user community in a specific area is currently being examined in the system test programs.

Return to Appendices

The need for bandwidth continues to increase as new applications are being developed to make use of broadband connections. The graphic on the right [6] illustrates the need for bandwidth for many of the current technologies. The current day home user is typically on the left of the graph with the applications being used adequately supported by one to three megabits service. The applications on the right of the graph move towards the needs of the business environment.



BPL appears to be capable of supporting the residential user's current requirement for bandwidth. The applications further to the right of the graph exceed the capabilities of BPL, in its present form, to support this user community.

In a BPL network, the user community is established by the number of homes supported by each transformer or nearby grouping of transformers. As bandwidth requirements in a specific user community grow, the BPL network must either 1) increase the speed of the network connection or 2) decrease the size of the user community. Current modulation schemes may limit the maximum speed of a BPL based link. Decreasing the size of the user community requires another fiber optic or similar link to segment the network into smaller user groups.

Conclusions

Technical issues continue to be discussed for the BPL technology. For example:

- *BPL Technologies have had limited success in Europe and Asia.* Many of the European companies that tried to offer commercial BPL have now abandoned the technology. In Europe, the power grid is more conducive to BPL. Household and business wiring are certified for proper grounding and a distribution transformer, on average, serves 250 customers compared to the United States where 20 customers or less is typical. Japan has effectively banned BPL.

- *In North America, BPL technologies are still in the pilot stage (under 100 homes).* Small pilots are not sufficient to properly gauge and monitor the effects of a widespread deployment. Some of the issues that need to be evaluated include are the effects of electromagnetic emissions; interference to other radio systems; Interference to distribution and transmission protective relaying.

- *Network performance with a large end user population is still undetermined.* Collisions and throughput reductions may be a problem as more users and subscribers obtain service.

- *Proven reliability and performance of components has yet to be determined* based upon the effects of surges, lightning and other forms of interference that is common in the power system.

This is the third wave of BPL vendors trying to enter the marketplace. The first and second wave vendors have disappeared or have abandoned their plans. Some of the third wave vendors may survive, but most probably will not. Each of the vendor offerings are proprietary, if the vendor goes, so does your investment.

Return to Appendices

Those seeking to adopt BPL technology for the delivery of widespread high-speed Internet services should proceed with caution. Evidence to date suggests that the more prudent course will be a regime of continued testing and evaluations. There remain questions concerning the underlying technology. Is BPL technology, as currently proposed, sufficient to effectively resolve issues of signal degradation and radiated electromagnetic noise? Has BPL hardware and software been designed to operate reliably in an environment where events such as power surges and lightening strikes are common? Evidence to date from Europe and Asia indicate reasons for concern. Current pilot projects in the United States are not as of yet a sufficient size to insure that BPL technologies are suitable for widespread deployment. We may find that over the succeeding months and years that these questions may be answered favorably. The deployment of a high-speed Internet solution through a ubiquitous and existing power grid infrastructure would certainly be of enormous national benefit. But competing claims by vendors and reasonable technological concerns suggest that the best course for electric utilities will be ongoing through assessments and a conservative approach to deployment.

Technology Implementation

Equipment cost	$225
Monthly cost	$40-60
Link distance	0.1-6Km
Line of sight required	No
Link speeds	500 Kbps
Implementation time	one day
Support effort	high
Support frequency	infrequent
SNMP-based monitoring	yes
Video support	minimal
IP telephony support	possible
Internet access support	yes
Support most LAN protocols	no

Usage Analysis

Short distance p-p	yes
Long distance p-p	no
Short distance multipoint	yes
Long distance multipoint	no
Mesh configurations	no

Interesting Websites

The vendor and organization Websites are shown in alphabetical order may provide additional information:

www.ambientcorp.com
www.amperion.com
www.currenttechnologies.com
www.homeplug.org
www.linksys.com/products
www.mainnet-plc.com

Return to Appendices

References

[1] http://www.currenttechnologies.com/. Current Technologies, LLC. is a manufacturer of PLC devices.

[2] Tilting at Power Lines by Christopher Helman. Forbes Magazine, Friday, January 3, 2003. More information can be found at: http://www.forbes.com/forbes/2003/0120/087.html

[3] Typical specifications for a Linksys Powerline EtherFast Bridge. For more information see the product specifications at: http://www.linksys.com/products/product.asp?grid=34&scid=33&prid=416

[4] Main.net Communication uses a series of carrier frequencies that allows the signal to pass through the transformer. It does still, however, require an active device to be placed at each distribution transformer.

[5] Source: Amateur Radio Relay League.

[6] Telework Consortium. www.teleworkconsortium.org

Return to Appendices

Introduction to Wireless Data Networks

Abstract:

Wireless data communications has changed significantly over the past decade. Wireless links to the Internet are appearing in public places, such as airports and restaurants. Wireless systems are being used to link nearby buildings as alternatives to a leased line. This paper will present an overview of the current wireless technologies and trends that may indicate the future direction of wireless systems and applications.

Introduction

Wireless systems used to create data-oriented networks are one of the most active areas of technology growth. Over the past three years some segments of the wireless industry have experienced substantial growth unlike other segments of the economy. This growth has created enthusiasm for new wireless technologies.

Since the introduction of the 802.11b[1] standard in 1999 the wireless market has out-paced other communications markets. The sales of PC and laptop wireless adapter cards are expected to reach 10 million[1] during 2003, only four years after the first product shipment.

Technology growth in the wireless area has created new approaches to communications. Standards-based systems began with speeds of 11 Mbps; this year the speed for the 802.11a system has increased to 54 Mbps. New approaches to wireless technology will lead to faster speeds. The recent approval of the ultra-wideband technology by the FCC[1] leverages the recent advances in technology to provide high bandwidth using an underlay approach to provide exceptional bandwidth over a small area. (An underlay service would be a wireless service that does not interfere with the predominant service over a range of frequency spectrum.)

This paper will categorize wireless into primary areas:

1. Fixed wireless systems
2. Mobile wireless systems

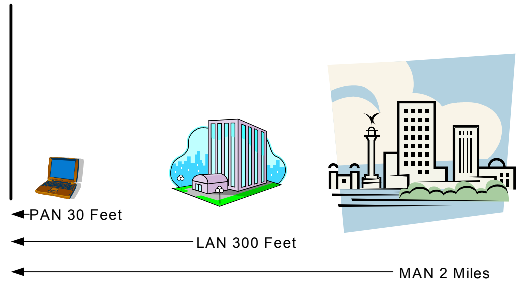
Systems in each of these areas are the focus of companies and standards organizations. This paper will review a range of wireless approaches that are both proprietary and standards-based in each wireless category. Some wireless equipment was designed for inside use within a building. Attachments have been developed that allow these devices to support external connections. This paper will focus on the use of wireless devices that provide connections in the external or outside environment.

[1] The 802.11 suite is often referred to as "WiFi."

Return to Appendices

Fixed Wireless Systems

Fixed wireless systems are available in a variety of configurations including point-to-point and point-to-multipoint. Point-to-multipoint systems use one or more points of concentration, the access point, and one or more remote nodes. In many cases a point-to-point link is a subset of the multipoint hardware platform. These systems are used to provide links between the access point and one or more remote users within in defined geographical area.



Fixed wireless system fit into three categories:

1. Personal Area Networks (PAN) that have a coverage area of less than 30 feet and provide connectivity to local user devices.
2. Local Area Networks (LAN) that have a coverage area of about 300 feet and building-oriented.
3. Metropolitan Area Networks (MAN) that cover areas with coverage area within two miles of the access point.

This section of the paper will cover the fixed wireless systems used to provide coverage in the MAN space. A central access point is used to provide Internet access for the local business and residential users.

The systems are commonly used as an alternative to high-speed data lines leased from the local telephone company and dial-up access. Wireless links are best used when buildings are located in a campus or small city setting where the link distances remain relatively short, usually less than one to two miles.

Wireless Networking Components

Wireless systems are composed of standards-based and proprietary approaches.

Standards-based Systems

Standards-based fixed wireless systems fall into two groups, 802.11x variations and the emerging 802.16-based systems (often referred to as "Wi-Max"). The 802.11x standards were developed to provide wireless systems supporting communications within a building. Through the addition of antenna systems and alternative packaging these systems have been expanded to provide external links between buildings. The 802.16 standard is being developed as an external wireless system. The IEEE 802.16 standard development group has optimized the specifications in the standard to support the longer link distances and interference found in an external environment.

Return to Appendices

802.11x Devices

The current devices built to support the 801.11 standard have three variations:

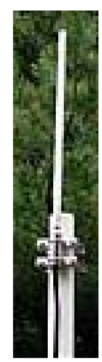
1. 802.11a
2. 802.11b
3. 802.11g

The first standards-based equipment to reach the market is based on the 802.11b standard that was approved in 1999. This system has a speed of 11 megabits per second with a typical throughput of about three [3] to four megabits per second. These systems operate in the 2.4 GHz frequency range.

The 802.11b-based systems and products have become very widespread in business and industry. They are now beginning to be deployed in the home as an alterative to using network cabling. The typical home access point may be purchase for less than $100 [2] with an interface card for the PC running about $50. This is very competitive with installation cabling or competitive products such as powerline carrier-based links.

The 802.11a-based systems and products have recently become generally available. These products have a raw transfer rate of 54 megabits with a typical throughput of nine to ten [3] megabits. These products are currently more expensive than the devices built to the 802.11b standard. These products operate in the 5.2 GHz to 5.7GHz ranges. With the higher frequency they are susceptible to the effects of walls and other structures that will limit the overall range. About twice as many access points will be needed to cover the same area as the 802.11b systems.

A hybrid system is based upon the 802.11g standard. The Network Interface Card (NIC) will identify and interoperate with either an 802.11a or 802.11b access point.



These standards-based systems have been designed and optimized to provide wireless service over relatively short ranges, less than 300 feet. Using different antennas, an access point can provide support for users in a larger area or for point-to-point links between two buildings. Various companies assemble antenna kits [4] that enhance the distance that can be supported. Some point-to-point links are advertised to support distances up to three miles.

802.16 Devices

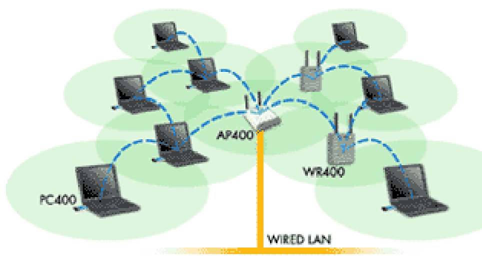
IEEE approved the creation of the 802.16 standard in April of 2002. The goals of this standard are to provide a framework for a wireless that that can provide high performance communications links in the first-mile. The standard focuses on the efficient use of bandwidth between 2 and 66 GHz and defines a Medium Access Control (MAC) layer that supports multiple physical layer specifications customized for the frequency band of use. In January of 2003 an addendum 802.16a standard was published that specifically targets the 2 to 11 GHz frequency band.

Return to Appendices

The 802.16 standard (actually composed of four variations a, b, c and d) is aimed at products that will provide connectivity in Metropolitan Area Network (MAN) environments where high bandwidth and Quality of Service (QoS) are required. The standard has been written in such manner to support a wide range of higher level protocols, such as Asynchronous Transfer Mode (ATM) and IP, at very high data rates, up to 268 megabits per second in a full duplex mode [5]. In April 2003 Intel [6] stated that they predict a coverage area of 30 miles and a wireless roadmap for the product in the near future.

Proprietary Mesh Networks

Mesh networking is a strategy that modifies existing wireless technologies to perform a repeater function in addition to being an end node in the network. This allows traffic to flow from station to station until it reaches the access point, effectively extending the range of the network components. Much of the technology that has been created to support this function comes from universities, such as MIT [8], or is developed and used by the military.



The illustration [7] above shows one product approach that is based upon modified 802.11b equipment. The system is composed of three components:

1. Access point. Labeled AP400 in the drawing it serves as the link between the wired and wireless LANs.
2. Router. Labeled WR400 in the drawing provides a dedicated hopping point between the access point and the client. It increases throughput of the network and extends range.
3. Client. Labeled PC400 in the drawing. The client provides access to the network and acts as a repeater for nearby stations.

The advantage of this network is it is self-healing because of the self-configuring and repeating nature of each node. If a device or link fails in a mesh network, messages are sent around the node using other devices. To improve redundancy additional wireless clients or routers are used to provide additional possible paths.

In similar fashion, installing additional access points can provide additional network capacity.

Mobile Wireless Systems

Mobile wireless systems have used either centralized fixed special purpose access points, or the cell phone system to provide low-speed data access. Many of these systems only provide speeds on the order of 19.2 Kbps supporting only terminal-based communications. Many of the current fixed systems are used by Public Safety employees to gain access into state operated systems. The cell phone system provides only short message service that provides text messages up to 150 characters in length or Cellular Digital Packet Data (CDPD) service running at about 19.2 Kbps.

Return to Appendices

Enhancements are being made to the cell phone system to provide higher speeds and additional services. The five largest cell phone providers [9] are in the process of upgrading their systems to provide higher bandwidth that will support enhanced data services with two approaches are being used, General Packet Radio Service (GPRS) or 1XRTT, by the various companies. The result will be data services that will provide between 30 to 70 kilobits per second. Although faster, the speeds are more like today's dial-up service with some additional latency and higher cost. When fully implemented, the cell phone network can be expected to provide Internet access for the next generation of Internet savvy cell phones.

Some applications require high-speeds than can be achieved using cell phone-based technology. Many times the geographic area needing service has boundaries, such as a city or county. Variations of mesh technologies are available to provide mobile access. One of the key problems with mobile access is the handoff from station to station and the issue of line-of-site.

Large numbers of users in a major metropolitan area need a system such as was built by the bankrupt Metricom. This system used a cell type of structure to track each user and performed a formal handoff of the data session as the user moved through the city. In addition, repeaters (shown above) were placed on utility poles to uplink the user device to the nearby wireless access point.

Systems with modest geographical size and user populations can use mesh-networking systems. These systems will reconfigure their links from point-to-point as the user moves through the area. Line of sight is another issue.

As frequencies move towards 2.4 GHz foliage and line-of-sight become an issue. The 2.4 GHz band cannot penetrate foliage and structures to maintain the link as the user moves. This may be overcome by placing repeaters, as shown in the example, at regular intervals so alternative paths are always available. Other vendors overcome the line of sight problem using lower frequencies.

Line-of-sight is not a great issue if the frequency is changed to 900 MHz[2]. Each station has a range of up to five miles with throughput varying with distance [10]. As this band is narrow, the throughput of these systems is significantly lower than high frequency systems. At one mile a throughput of about 1 Mbps is possible and by three miles throughput is down to about 500 Kbps or slower depending upon conditions. Using repeaters at regular intervals will allow mobile users in a small city to always have broadband access.

[2] Pine trees, however, tend to absorb 900 MHz RF radiation.

Return to Appendices

Technical Direction

Fixed Wireless

New technologies such as software defined radios and ultrawideband have the capability of providing very high-speeds supporting the first-mile link. These technologies are still in the testing phase as proof-of-concept.

The recently approved 802.16 standard and its variations has the greatest capability in the near term to provide equipment that has an impact on the MAN system that 802.11-based technology had on the LAN systems. Chip sets and interoperability test suites are being developed to support product introductions in the near future.

Mobile Wireless

The IEEE has setup a standards group to develop mobile wireless systems, the 802.20 committee. The committee's charter is to develop IP-friendly mobile specifications that provide the mobile users traveling at high-speeds service levels that are comparable to wired broadband systems, such as cable and DSL connections. Providing mobile broadband networking, based on cell ranges of about 10 miles, the new standard will provide the platform for mobile interactive voice, video and data services. This group was formed in March 2003

Technology Implementation

Equipment cost	Low
Monthly cost, video	n/a
Monthly cost, HS data	$40
Link distance	1-2 miles
Line of sight required	yes
Individual link speeds	3 Mb
Implementation time	quick
Support effort	low
Support frequency	as needed
SNMP-based monitoring	yes
Video support	limited
IP telephony support	limited
Internet access support	yes
Support most LAN protocols	no, IP only

Usage Analysis

Short distance p-p	yes
Long distance p-p	yes
Short distance multipoint	yes
Long distance multipoint	yes
Mesh configurations	yes

Return to Appendices

Interesting Websites

The vendor and organization Websites are shown in alphabetical order may provide additional information:

www.newamerica.net
www.meshnetworks.com
www.motorola.com/canopy
www.nova-eng.com
grouper.ieee.org/groups/802/20/
www.ieee802.org
standards.ieee.org/getieee802/802.16.html
standards.ieee.org/getieee802/802.11.html

References

[1] Open Spectrum, The New Wireless Paradigm. New America Foundation, Spectrum Policy Program. http://www.newamerica.net/index.cfm?pg=article&pubID=1001

[2] TigerDirect.com catalog Volume XIII, Issue ACA. Pages 74 through 79 with products from various manufacturers.

[3] "Faster Wireless Networking" PC Magazine, June 11, 2002. The full article may be found at: http://www.pcmag.com/article2/0,4149,701,00.asp#table

[4] The antenna shown supports 802.11b systems and is available from HD Communications. Further information is available at http://www.hdcom.com/links.html

[5] "Technical Information-Overview of IEEE 802.16" found at the WiMAX Forum Website at http://wimaxforum.org

[6] Intel to Unveil 'next big thing' in wireless. Computerworld Magazine, April 8, 2003. The article may be viewed at http://www.computerworld.com/mobiletopics/mobile/technology/story/0,10801,80145,00.html

[7] Mesh networking product examples. Descriptions based upon products and text on the Website for Mesh Networks. More information may be found at: http://www.meshnetworks.com/pages/products/meshlan/components.htm

[8] Wireless Mesh Networks. www.sensorsmag.com for February 2003.

[9] Wireless Nirvana. Network Computing Magazine, October 21 2002, pages 67 through 78. The article is also available online at www.nwc.com

[10] Product specification for NovaRoam 900 Wireless Router. Nova Engineering, Inc. Further information may be obtained at www.nova-eng.com

Return to Appendices

Analysis of Fiber Optic-Based Technology

Abstract:

Communications systems based upon fiber optic technology are all around us. Links between home entertainment devices, links for high-speed communications between cities and between continents are a few of the uses for this media. Fiber optic cable and unshielded twisted pair cabling are the two predominate cable types within the United States. We expect that companies providing our voice, data and television programming use fiber optics for at least part of the transport. However, fiber optics has yet to become the predominate media for the last-mile to our homes and businesses. Fiber-to-the-Premises and Fiber-to-the-Business are only beginning to occur as tests or in small communities. This paper will discuss the characteristics of fiber optics that make this the clear media choice for the future.

Introduction

Fiber optic-based media has rapidly become the key infrastructure component of the modern communications system considering it only began by carrying modest amounts of telephone traffic in 1977 [1]. Every aspect of the modern communications system can use fiber optics including telephone, cable television and data communications systems. As the use of fiber has increased the price of fiber has decreased to a point it has become the media of choice.

Many of fiber optics characteristics make if a very desirable media. Unlike copper-based technologies, fiber optics is immune from interference caused by radio frequency and magnetic sources.

Crosstalk caused by nearby radio transmitters or electromagnetic sources, such as arc welding or lightning, have no effect on a fiber because of its nonmetallic structure. In addition to its electrical characteristics, fiber is immune to the action of most chemicals and water. Damage to a fiber optic cable is usually caused by a physical attack on the cable.

Many communications system utilizing fiber optics can be consider “future-proof” with high-speed being implemented by merely changing the end devices. One example of this type of technology is Dense Wave Division Multiplexing (DWDM). Many of the fiber optic systems carrying traffic between cities was thought to be approaching traffic saturation only 10 years ago. DWDM now allows a fiber optic cable to carry almost 100 times the traffic over the same cable.

Along with the capability to carry more traffic comes increased reliability for the network. Miles of continuous fiber optics have replaced analog devices and copper cable in telephone and cable television networks. With no active device placed periodically in the cable, fiber optic systems only have an active component at each end of the cable. These systems need have infrequent need for preventive maintenance. The most common problem in a fiber optic-based system is a break in the cable caused by an accidental cut during underground construction or an auto hitting a pole for aerial systems.

Return to Appendices

The implementation of fiber optic technology in the first-mile is currently hindered by investment in legacy copper-based systems and lack of investment capital that is available to commercial communications providers. High debt loads from consolidations and the current economic climate have delayed the replacement of copper-based system with those based upon fiber optics. Many of the fiber optic systems being built today are systems owned by municipal utilities.

Technical Description

Spectrum

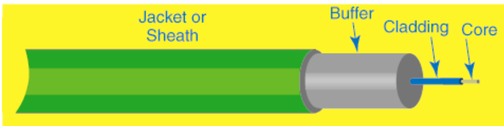
Fiber optic cable is composed of glass that is manufactured in a manner that promotes the transmission of light in near ultra violet frequencies. As the chart below shows, the UV band used for fiber optic-based communications is just above the frequency that our eyes can detect.

At these frequencies the fiber can be made where the properties of the cable cause light to bend, or reflect, and go through the cable with very little loss.

As the picture above illustrates, the light enters one end of the fiber and bends as it propagates through the fiber to the opposite end.

Cable Construction

Depending upon the type of fiber, singlemode or multimode, a laser transmitter or LED-based transmitter is placed at the sending end with a photodiode placed at the receiving end of the cable. The transmitter is responsible for converting the electrical energy to optical energy with the receiver converting optical energy to electrical energy.



The illustration above shows four of the five component parts of a typical fiber optic cable. These components are:

1. Core. Light is injected into the core. It forms the primary path for the optical energy.

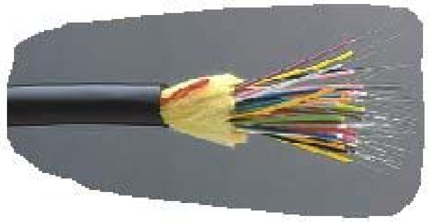
2. Cladding. The cladding is wrapped around the core to provide a reflective or refractive surface to create a light pipe in conjunction with the core.

3. Buffer. The buffer coating is typically a 900 micron coating of plastic to protect the fiber.

4. Jacket. The outer jacket protects the cable and provides a location where identifying information can be printed.

Return to Appendices

5. Kevlar. Most fiber cables have Kevlar added to provide strength to the cable.



Multifiber cables are made by assembling many individual fibers into larger groups, wrapping the individual fibers with Kevlar yarn (yellow in the illustration above) and encasing the components with a common plastic sheath. This is a basic description of a fiber optic cable. Many cables are made to work in specific applications and may have additional components, for example a stainless steel layer for abrasion resistance, to meet the needs of a particular user community.

Types of Fiber

Two types of fibers are in use today, multimode fiber and singlemode fiber.

Multimode

Multimode is predominately used in buildings with lower cost LED-based components with bandwidth and distance requirements are modest. The typical size of multimode fiber is about 62 microns (millionths of an inch) for the core and 125 microns for the cladding. Multimode fiber provides support for a wire spectrum of light running from near 800 nanometers to about 1,600 nanometers. The typical length for multimode fiber is less than two kilometers.

Typical applications for multimode fiber cable include short runs between devices, data connections between floors in a building and data links between buildings. Links with multimode fiber are implemented for a number of reasons including provide very high bandwidth over short distances, eliminate the possibility of RF interference and differences in ground potential. Fiber optic links between buildings is the chief method used to eliminate damage to the network should a nearby lightning strike occur. A metallic link would induce considerable energy into the building network leading to failures of network components and computers.

Different ground potentials between buildings can cause problems when metallic cable is used to link the buildings. Buildings in a campus environment may receive power from widely separated power transformers. It is not uncommon for different buildings to have a different ground potential because of soil conditions where the ground point is established. If a copper link is used between the buildings a current flow may result that create electrical noise. On a different scale, a nearby lightning strike can induce a large current in a copper cable that caused failure or destruction of the connected equipment. Fiber optic cable does not exhibit these characteristics as the cable is non-conductive.

With multimode fiber optic cable the typical applications are data-oriented. The LAN-to-LAN link for 10/100/1000 Mbps Ethernet link is commonly run between floors of buildings and building to building using the lower cost multimode fiber optic cable and attached conversion devices.

Return to Appendices

Singlemode

Singlemode fiber is used with laser transmitters and is used where high-speeds, multiplexing (CWDM and DWDM) and longer distances are required. Singlemode fiber has a small core size of about eight microns with a cladding size of 125 microns. A smaller range of light frequencies is supported with laser-generated light supported between the frequencies of 1,300 to over 1,600 nanometers. As network technology move toward higher speeds and more complex applications singlemode fiber will become the choice for almost all applications.

Singlemode fiber optic cable has more applications because of its capability to support higher bandwidths and longer distances. Some of the applications include:

1. Analog video, voice and data distribution by CATV companies.
2. Long-haul voice and data transmission between cities, states, nations and across oceans.
3. High bandwidth data applications such as Storage Area Networks, SONET-based links and links using the emerging 10-gigabit Ethernet equipment. Many of these systems are being implemented by private business to distribute resources within a campus environment and provide backup resources

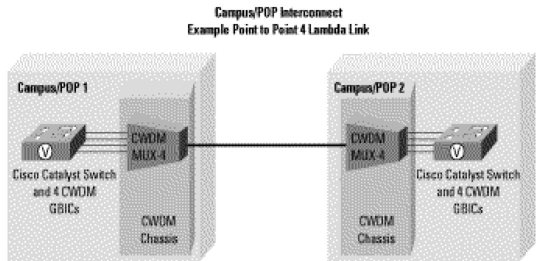
Optical Multiplexing

Singlemode fiber has a very promising future through the use of multiplexing technologies. Course Wave Division Multiplexing (CWDM) and Dense Wave Division Multiplexing (DWDM) are two technologies that currently can expand the amount of traffic a single fiber can carry by more than a factor of 100.

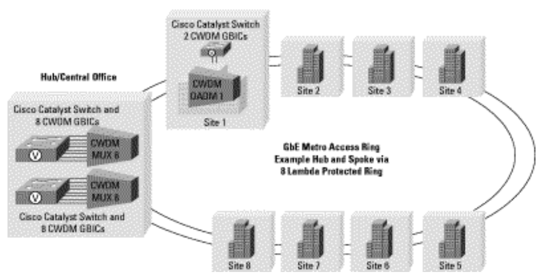
Course Wave Division Multiplexing (CWDM)

CWDM transports traffic using lower cost components that use widely space optical frequencies. As an example [2], the Cisco Systems equipment shown above can support eight Gigabit Ethernet connections over two singlemode fibers. Each pair of modules operates at a different frequency between 1470 nanometers and 1610 nanometers. Each channel is spaced at 20 nanometer increments (1470 nm, 1490 nm, 1510 nm, etc.).

Return to Appendices



A typical configuration shown above [2] shows where one to eight networks are connected to the multiplexer transported over two singlemode fibers (one transmitter and one receiver) and demultiplexed at the remote end. This approach provides a significant savings compared to the construction of addition fiber optic resources to transport additional traffic.



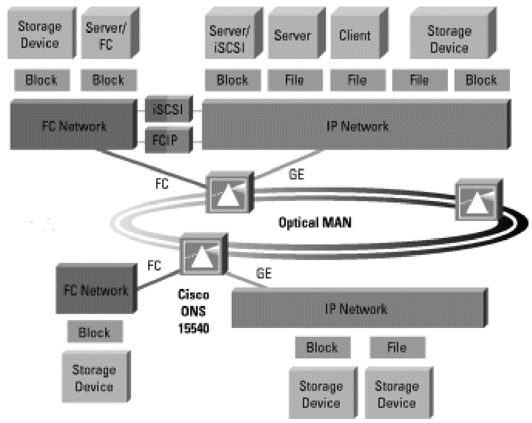
More complicated architectures can be created as shown in the illustration [2] shown above. The CWDM multiplexer can create point-to-point links over a common network using a different optical frequency. Although the network topology is a physical ring, the logical topology is a star beginning at the sending site, on the left, and linking each remote site, those on the ring, with a particular frequency of light. This type of topology is well suited to linking remote facilities using Gigabit Ethernet.

One of the factors that differentiate CWDM technology is its cost. CWDM costs 40 percent less than the same number of channels using DWDM technology. This is especially attractive for short-haul optical networks in urban areas where little excess capacity exists [5]. More capacity can be squeezed from existing fiber consistent with economic justification.

Dense Wave Division Multiplexing (DWDM)

DWDM is a similar technology to CWDM that uses optical frequencies that are closely spaced, 0.1 to 0.2 nanometers for example. Significant amounts of traffic and types of traffic can be carried using DWDM. This technology is applicable for geographic areas where traffic can be concentrated for transport into a common backbone network.

Return to Appendices



The above illustration [3] illustrates the concept of a Metropolitan Area Network, MAN, being composed of three DWDM multiplexers with linking fiber optic equipment. Two of the facilities are linked to support Fiber Channel-based applications, for example a Storage Area Network, and two facilities links using Gigabit Ethernet for LAN-to-LAN support of data and IP-based voice applications.

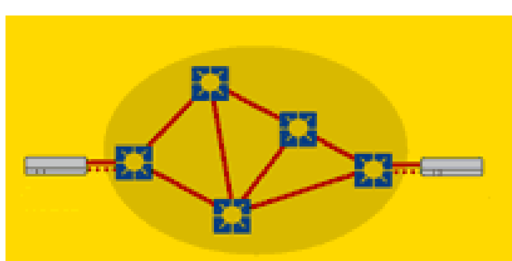
This particular example using the Cisco ONS product is capable of supporting 32 different channels of Gigabit Ethernet or 320 gigabits of traffic. Other manufacturers [4] provide platforms that can support up to 160 optical wavelengths, or lambdas, with a combined bandwidth of 800 gigabits. This traffic can support a wide range of traffic types such as SONET, Fiber Channel, Gigabit Ethernet, ESCON, FICON and others.

Both CWDM and DWDM systems are alternatives to implementing additional fibers in a network. For the telephone companies, this means that the current fiber optic links running between central offices and cities have more than enough capacity to support application growth for the foreseeable future. Building a new fiber optic network requires a different perspective.

The cost of building a fiber optic cable plant is 10 percent fiber cable and 90 percent path related costs, such as a trench or placement on poles. The typical cost for a six-fiber cable is about 40 cents per foot. A 200-fiber cable cost about $2.50 per foot. At this point in the technology curve, multiplexing technology costs must be evaluated against the cost of additional fibers in the cable. Lower installation costs, such as aerial cabling, may show a larger cable to be the best choice. During the design process each technology must be evaluated to develop the best combination of price and technology.

Technical Direction

Fiber optic technology continues to be a rapidly changing environment despite the current economic climate. One of the technologies that may change the direction of fiber optic technology is optical switching, also call lambda switching.

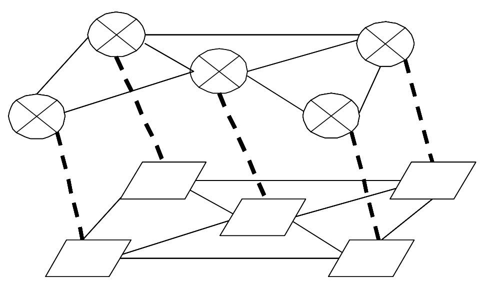


Return to Appendices

Lambda switching will lead to intelligent networks that can switch light in a manner similar to the way we switch data packet today. The illustration above shows a source of data, on the left, enters the network using a specific lambda. This lambda is dynamically switched through the backbone optical network and delivered to the destination, on the right. Should a cable be cut or a device fail the network will be capable of automatically rerouting the lambda through a different optical path within a redundant backbone network.

Standards bodies are working with academia and manufacturing companies to expand the knowledge base in fiber optics. Many of the concepts using in our existing networks, such as routing and switching, are being expanded to seamlessly include emerging optical systems. In the future [6] routers can be expected to interface with optical switches and move data on different physical optical paths, both by a particular fiber and lambda, much the same as data is routed through today's networks. Consider that one year ago one fiber could support [6] 10 gigabits per lambda and 64 lambdas per fiber. Current products can [4] support 160 lambdas per fiber. Predictions are that today's fiber optic cable is capable [6] of supporting as many as 1,000 lambdas with technology in sight where each lambda will support a 40-gigabit data link.

To accomplish the expansion of router capabilities new routing protocols will need to be created. Protocols such as GMPLS [6] will allow the seamless connection of electronics and optics with switching to allow the routing of data at high-speed in complex electronic and optical-based networks.



Router Optical Switch

The drawing above [6] illustrates how routers will form the control plane for the underlying optical switch. The implication of this configuration shows that any service that can be digitized may be carried through an all-optical network at high-speed. Today's routers would be used to aggregate traffic at the edge of the optical network or provide packet-oriented switching before entering the optical stream.

Future applications for optical networks include applications on demand, high bandwidth with a quality of service requirement, and aggregated data streams between two end points.

Technology Implementation

Equipment cost	substantial
Monthly cost	$0
Link distance	0-120Km
Line of sight required	no
Individual link speeds	0>40Gbps
Implementation time	extended
Support effort	high
Support frequency	infrequent
SNMP-based monitoring	yes
Video support	yes

Return to Appendices

IP telephony support	yes
Internet access support	yes
Support most LAN protocols	yes

Usage Analysis

Short distance p-p	yes
Long distance p-p	yes
Short distance multipoint	yes
Long distance multipoint	yes
Mesh configurations	yes

Interesting Websites

The vendor and organization Websites are shown in alphabetical order may provide additional information:

www.cisco.com
www.nortelnetworks.com
www.spectrum.ieee.org

References

[1] http://www.sff.net/people/Jeff.Hecht/chron.html. A short narrative on the chronology of events in the history of fiber optics. The author is Jeff Hecht. He has also written a book on the subject titled *City of Light: The Story of Fiber Optics.*

[2] http://www.cisco.com/en/US/netsol/ns110/ns112/ns113/ns197/netbr09186a00800fd6d5.html. Cisco Systems CWDM product specification sheet.

[3] http://www.cisco.com/warp/public/cc/pd/olpl/metro/on15500/on15540/prodlit/fdmte_an.htm. Application Note: DWDM Technology for Storage Networking and Disaster Recovery.

[4] http://www.nortelnetworks.com/products/01/optera/long_haul/1600/index.html. Nortel Networks: OPTera Long Haul 1600 Optical Line System.

[5] http://www.spectrum.ieee.org/spectrum/aug02/departments/nmetro.html. New Global Standard Set For Metro Networks. The author of the article is Michael J. Riezenman.

[6] http://www.evl.uic.edu/activity/NSF/ppt/LEHMAN_FINAL_LambdaSwitching.ppt Tom Lehman, PowerPoint presentation on Optical Switch presented by the University of Illinois.

Analysis of Free Space Optics Technology

Abstract:

Free space optics, or a laser-based communication, is a technology being implemented to provide high-speed communications over short distances. This article describes the use of an optical link to overcome nearby physical barriers and how some vendors are using parallel technologies to overcome problems of fog that can interfere with communications.

Introduction

Free space optics is one of the communications technologies that can provide high-speed communications, LAN speed, over short distances of one to six kilometers. Physical barriers to communications links take the form of both natural barriers, such as rivers, and artificial barriers, such as railroad tracks or lack of easement rights. Historically, a communication link is leased from a public provider, such as the local telephone company, with the franchise to provide communications services to cross these barriers. Free space optics may be an alternative to public carriers.

In recent years the cost and performance of links from public carriers may not be the optimum approach to cross a barrier such as a street or river. The typical cost of a T1 line, running at 1.5 Mbps, is about $750 per month and the T3 line, running at about 45 Mbps, can be nearly $10,000 per month. Many times this cost is paid to link two buildings that are less than 1,000 feet apart with a clear line of sight.

Consider the impact of installing a link from a public carrier on the overall performance of the network. It is not unusual to run floor-to-floor links using gigabit Ethernet and desktop links using 100 Mbps Ethernet. Lower speed links between buildings limits the overall functionality of the network in terms of program functions, backup scenarios and disaster planning.

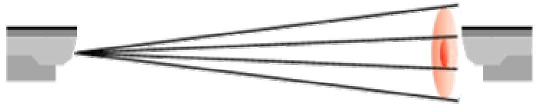
Free Space Optics (FSO) can be used to link networks at full speed, such as gigabit Ethernet, over distances up to 500 to 1,000 meters with a quick payback period when compared to similar facilities from the public carriers. Systems are available with speeds ranging from T1, 1.544 Mbps, up to OC48, about 2.5 Gbps.

Technical Description

Free space optics is based upon using a laser transmitter pointing at a receiver with a photo diode. This is similar to the technology used with fiber optic links where lenses replace the fiber optic cable.

Return to Appendices

Link Components



The drawing above illustrates an optical transmitter sending a beam of light that is modulated, or carries, the data to be transmitted to the remote end of the link. In most cases, each unit contains both a transmitter module and a receiver module to form a transceiver unit that is capable of forming a link in both directions. Bi-directional support is important as data must be moved in both directions over the network link.

Operability Factors

A summary of key factors [1] that influence the operability of an optical link is:

- Transmitted power
- Beam divergence
- Area of the receive aperture
- Atmospheric attenuation
- Link length

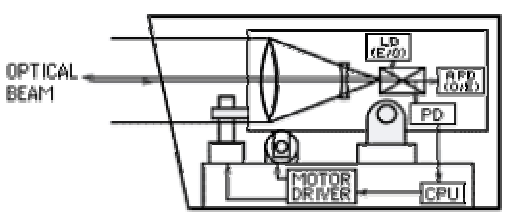
Each of these factors influences the design of a vendor's product with atmospheric attenuation and link length having the largest influence on link operability, or reliability. To develop a system that can provide carrier class reliability, an uptime of 99.999 percent, the system designer will devise a component system that attempts of compensate for unpredictable atmospheric conditions, like fog, while maintaining a usable link length that customers will purchase. To some extent the power of the laser can only be an increased to a point as there is a threshold where the beam becomes a hazard.

Atmospheric conditions fall into several categories [2]:

- Wind
- Heat
- Fog and rain

Wind

Optical links developed in the 1980s needed a line of sight so precise that the building swaying in the wind or a train passing on adjacent tracks could disrupt the link. Vendors overcame these problems by using tracking systems or using approaches that widened the beam being transmitted.



Return to Appendices

The Canon Canobeam [3] uses the system in the picture above to provide up to four degrees of change along both the vertical and horizontal axis. As the mounting of each unit varies with the wind or because of vibrations changes will be made with motors to maintain beam alignment end-to-end.

Another vendor, Sona Optical Wireless, overcomes the wind and vibration problem using multiple transmit lasers that spread the beam around the receiver location. The product specifications show carrier grade operability in winds up to 75 miles per hour at distances beyond two kilometers.

Heat

Beyond wind and vibration, heat causes an effect called scintillation where the air visibly shimmers, the cause of the stars twinkling appearance. Zones of air with differing densities act as lenses that scatter the light from the desired path. This causes fluctuations in signal amplitude as the beam wanders around the receiver. One vendor’s approach to this problem [5] is using multiply beam transmitter to provide a larger signal area at the receiver. Another vendor, Aoptix, [2] uses active optics to continuously adjust the characteristics of the FSO beam. Active optics uses small flexible mirrors to correct for scintillation in real time to nearly resolve this problem.

Fog

Fog is the major challenge to FSO-based communications. Rain and snow have little effect on FSO, but fog, a vapor composed of water droplets only a few hundred microns in diameter, can modify the characteristics of light or completely hinder the passage of light through a combination of absorption, scattering and reflection. One vendor’s whitepaper [1] outlines testing performed using a variety of variables such as transmit frequencies, receive aperture sizes and different beam divergence sizes to identify the range of an FSO link when a fog was present the presented a 100 decibel per kilometer loss. The conclusion reached was the best approach to maintain carrier grade service in a fog environment was to reduce the length of the link to 500 meters.

Return to Appendices

Another provider [1] takes a different approach to maintaining the link during a heavy fog condition. AirFiber uses a 60-gigahertz radio link running parallel to the optical link. The radio link will experience a 16-decibel loss per kilometer because of oxygen absorption. This limits range [1] to about 1,500 meters for the radio link. The two links have offsetting strengths, or a symbiotic relationship, that make this a good match. Both systems are unlicensed, the optical link is not effected by rain where the radio is effected, and the optical link is effected by fog where the radio link is not effected by fog. AirFiber [1] monitors link integrity of both links and selects the best performing link, packets with correct CRC checks, for the current weather conditions. As an example of the expected operability of this approach, an AirFiber survey [1] shows a link length of 1,500 meters can be expected to provide a reliability of 99.95 percent. The AirFiber approach is illustrated below.

Other Issues

Unlike laser communications in space where the beam can travel from the Earth to the Moon, the characteristics of the Earth atmosphere limit the effective distance with laser communications where safety considerations limit power. Absorption in the atmosphere occurs when water molecules suspended in the air extinguish photons. This causes attenuation in the FSO beam. Scattering is another problem [6], specifically MIE scattering, where particles floating in the air. These particles cause "a directional redistribution of energy that may have significant reduction in beam intensity for longer distances" [5].

Technical Direction

The free space optical products market continues to grow as new applications and higher bandwidth capabilities are developed. FSO technology is targeted at the metropolitan area where links can be developed between buildings with only modest, two to six kilometer, distances separating the facilities.

The unlicensed nature [6] of the product throughout the world allows standardized solutions to be developed for the delivery of high-speed, up to 2,500 gigabits, links over the last-mile. One report states [5] "only five percent of buildings in the United States are connected to fiber optic infrastructure, yet 75 percent are within one mile of fiber." Organizations can purchase and install equipment on their buildings that allows the creation of a business like park network without the need for fiber optic cable and the related construction costs. This is of particular benefit in center city areas of large cities where construction of a fiber optic link maybe expensive or not available. FSO can be used to link area buildings in nearby areas as-long-as line of sight is available.

Return to Appendices

Although FSO systems are relatively easy to install, deployment parameters [6] must be considered. Beyond physical installation of the equipment, consider the following parameters:

1. Link length versus reliability with shorter links having higher reliability than longer links.

2. Meteorological visual range.

3. Weather parameters for the area including temperature, normal humidity, air pollution and fog model.

Current laser-based free space optics technology is providing links speeds of 2,500 megabits. One company [7] is researching new approaches that will lead to terabit laser systems that are capable of supporting 1,000 times more speed than today's systems with links as long as 10 kilometers. Along with higher speeds is the investigation of approaches to increase distances in the presence of fog. These technologies remain in the test stages and will not likely be commercial products for several years.

Technology Implementation

Equipment cost	15-100K$
Monthly cost	$0
Link distance	.1-6Km
Line of sight required	yes
Link speeds	0>2.5Gbps
Implementation time	one day
Support effort	high
Support frequency	infrequent
SNMP-based monitoring	yes
Video support	yes
IP telephony support	yes
Internet access support	yes
Support most LAN protocols	yes

Usage Analysis

Short distance p-p	yes
Long distance p-p	no
Short distance multipoint	no
Long distance multipoint	no
Mesh configurations	yes

Return to Appendices

Interesting Websites

The vendor and organization Websites are shown in alphabetical order may provide additional information:

www.airfiber.com
www.aoptix.com
www.astroterra.com
www.canobeam.com
www.fsona.com
www.holoplex.com
www.plaintree.com
www.irlan.co.il
www.terrabeam.com
www.wcai.com

References

[1] http://www.airfiber.com/products/HFR.pdf. The Last-Mile Solution: Hybrid FSO Radio. The authors are Scott Bloom, PhD and W. Seth Hartley, MS, of AirFiber, Inc.

[2] www.networkmagazine.com/article/nmg20020826s003. Wireless Optics: Fiber Is Cheap, But Space Is Free. Network Magazine September 4, 2002. The author is Andy Dornan.

[3] http://www.canon.com/bctv/canobeam/. Canobeam Technology description.

[4] http://www.fsona.com/product.php?sec=155m Sona Optical Wireless product description.

[5] http://www.freespaceoptics.org/index.cfm/fuseaction/content.WhitePapers. A white paper titled “FSO Insights” authored by LightPointe.

[6] http://www.ulmtech.com/Downloads/UlmTech0122.pdf Simulating Atmospheric Free Space Optical Propagation. The author is Maha Achour, PhD

[7] http://www.attochron.com/dwnld/Attochron.pdf Attochron, LLC. PO Box 5025, Playa Del Rey, CA. Femtosecond Laser Air-Ionization for Free Space Optical (FSO) Communications and FSO Power Delivery. The author is Tom chaffee.

Introduction to Fiber-To-The-Premises Networks

Abstract:

Fiber-to-the-premises (FTTP) systems are the next evolution in last-mile communications. The use of fiber optics provides the bandwidth needed to support the consumers and businesses need for voice, video and data services. These systems are only at the beginning of the adoption curve. This paper will describe the state of the art in FTTP systems and show examples of the application of FTTP.

Introduction

Fiber-to-the-premises (FTTP) and fiber-to-the-business (FTTB) are the natural evolution of the Hybrid Fiber Coax (HFC) cable plant taken to an all fiber optic configuration. Although envisioned by the manufacturers of FTTP systems as a replacement for the current HFC architecture, most of the cable operators have little interest in this technology [1] as they have a significant investment in HFC or other copper-based systems and a shortage of capital for infrastructure improvements.

Most cable operators believe that their existing HFC systems have adequate bandwidth to meet the current product lineup and the more bandwidth intensive applications such as high-definition television.

FTTP has growing appeal to municipalities and utilities that are building new systems and do not have an existing cable plant architecture. Approximately 400 systems are using FTTP worldwide with a little over 10 percent of the systems in the United States [1]. Analysts expect this market to continue to grow a compounded rate of beyond 50 percent over the next four years [1].

FTTP Network Topology Overview

Most FTTP networks have a similar topology. One or more fibers leave the headend or central office carrying a variety of signaling. Different vendors have approaches that vary depending upon the technology of their approach. Figure 1 illustrates the basic approach to an all fiber optic networks.

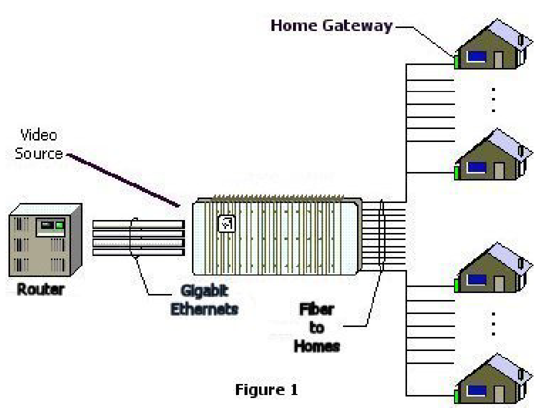


Figure 1

Return to Appendices

The component areas shown in Figure 1 from left to right include:

- Headend and central office components. This is the local point of concentration for voice, video and data at the center of the network. These devices drive the various fiber optic network systems distributing content. Content is obtained from many sources and groomed into a cohesive programming and services offering. Other ancillary systems may be located here including network provisioning, network management, customer call centers, etc.

- Cable plant and Media Concentrator. Fiber optic cable links the headend or central office with the user community. Fiber optic cable is the key component in this network. Different vendors use various technologies during the delivery process. Some technologies, such as Wave Division Multiplexing, target the amount of fiber that is required between the central office and the end user. The local media concentrator is an optional active device depending upon the technical architecture of the system. If used, this device contains local electronics, such as an Ethernet switch, and optics to support 100 or more homes. Services will be delivered from the local concentrator over one, two or three fibers depending upon the technologies used by the vendor.

- Optical Tap. The optical tap splits the optical signal to a small number of homes. Some vendors only use this device for the fiber supporting video (CATV) signaling. A layer two Ethernet switch is used for the data-oriented content. The optical tap splits the fiber path near a small group of homes from one input to four or eight outputs.

- Premises Point of Presence. This is an interface unit placed on the side of the house. This unit provides conversion between fiber optic cable, input, and copper media, output, used in the home. It is commonly called the Optical Network Unit (ONU).

Each vendor will use these components along with different fiber optic cable topologies to provide a cable plant system that is cost effective and capable of meeting the current and future needs of the provider and local community. In general, most carriers believe their current copper and fiber networks are adequate to meet future demands [1]. The FTTP systems have become most popular with carriers that are building new cable plants where an existing copper-based cable plant cannot be modified with shorter runs of fiber, such as an HFC approach, to provide more bandwidth and services to the end user.

FTTP Cable Plant Components

The typical FTTP system is composed of several key large elements:

Headend or Central Office

This is the local point of concentration for all content such as voice services, broadcast video (CATV), video on demand, high-speed Internet, security and other services depending upon business plan of the provider. A headend unit interfaces between the content providing devices or sources and the fiber optic cable that delivers programming and services to the customer base. Figure 2 illustrates the link that the headend or central office performs in the FTTP system.

Return to Appendices

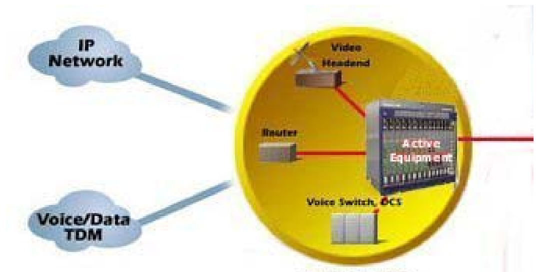


Figure 2

As Figure 2 illustrates, the central office serves as the focal point for external links, such as the IP-based Internet and the traditional voice and data network. Local equipment is placed in this facility including the video headend, video servers, Internet-oriented servers and telephone equipment. Specialized active equipment will link the local and external networks to the fiber optic cable plant that will support services to the local homes and business communities.

Different companies use alternative approaches to the interface unit between the headend or central office components and the fiber optic cable plant. One company has a combined unit that provides a link to telephone services and data services in the headend and the fiber optic cable plant. A separate video transmission is provided by standard HFC equipment over a separate FTTP. Still other vendors use Wave Division Multiplexing (WDM) technology to merge services on to a single fiber.

Vendors fall into two technical camps:

1. APON or ATM-based Passive Optical Network
2. EPON or Ethernet-based Passive Optical Network

The APON group uses ATM signaling at a rate of 155 Mbps to provide support for voice and data services. The EPON approach relies upon the use of Gbps Ethernet (gigabit Ethernet) to support the same services. Each approach attempts to use similar fiber optic components and technologies to deliver content to the end user at the lowest cost per home possible.

Typical Vendor Equipment

Figure 3 illustrates a controller that provides the interface between the external voice and data networks and the FTTP cable plant. Typically, this approach supports more than 1,000 subscribers providing voice and data support. Voice and data traffic is supported on the fiber optic cable plant using either one or two fibers to each end station.

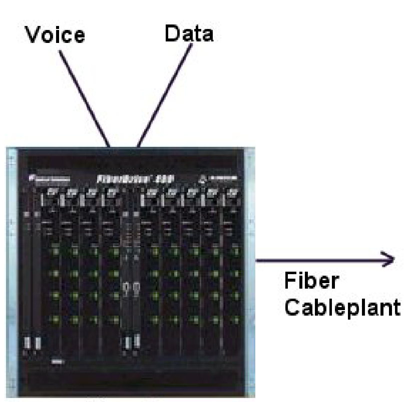


Figure 3

Return to Appendices

As voice and data traffic is mixed, priority for time sensitive traffic is achieved using signaling similar to an ATM-based network or a Quality Of Service (QOS) approach within the IP protocol.

In some cases, selected video content will be placed on the data path in the form of IP-based content. Usually video programming moved in this manner is video on demand taking the form of streaming video using the IP transport.

CATV-based video programming is broadcast using the same type of transmitter [4] used in a typical HFC type of cable plant system. However, as the fiber goes directly to the home or business a receiver must be placed at each building to convert the signal back to the common coax-based link expected by the television receiver.

Another approach uses an open architecture for video and data devices in the headend interfaces. Data and voice will be distributed to the cable plant using a gigabit Ethernet interface supported by equipment from common equipment vendors such as Cisco System, Nortel and others. Using the Ethernet approach, voice can be supported using IP-based telephony equipment to each resident. This same path will provide distribution for Internet access, video on demand and a range of other possible services. The key to this approach is providing high bandwidth to the home and using equipment that supports QOS. A separate fiber will be used to distribute broadcast video from a transmitter commonly used to drive an HFC CATV cable plant, such as the one shown in Figure 4. It is not uncommon for vendors to place an intermediate multiplexer in the cable plant to concentrate all services on to one fiber using WDM technology. This approach is called a local node.

Figure 4

Return to Appendices

Local Node

The local node controller [2] serves as the concentration point for the local residential and business customers. Fiber links from the headend or central office are transported to the local node over several individual fibers. Figure 5 provides an example of one type of local node controller. Two fibers may support one or more gigabit Ethernet links and one fiber for broadcast video. At the local node several types of processing may occur depending upon the vendor design:

Figure 5

1. The fibers supporting a gigabit Ethernet link are connected to a layer two switch.
2. The fibers supporting broadcast video are connected to one or more optical splitters.
3. The output of the layer two switch connects to a fiber running to a residential POP. Both transmitter and receiver may be combined on one fiber using WDM technology.
4. The output of an optical splitter connects to a fiber running to a residential POP. This signal may be combined on the fiber supporting the data connection by using WDM technology.

Depending upon the vendor, the local node may take many forms. Some approaches including the form factor shown in Figure 5 that is similar to that of a typical fiber node used by the CATV companies. Other vendors have a device similar to that shown in Figure 3 that is placed in a vault. Depending upon the approach, fiber will run from the local node to the residential gateway. The link will either be direct from the node or be split one more time using an optical splitter.

Optical Tap or Splitter

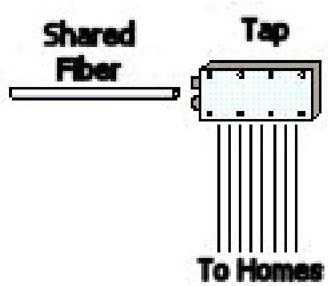


Figure 6

Return to Appendices

The optical tap shown Figure 6 takes one fiber and splits it into four or eight fibers. This is a passive device, requiring no power, similar in function to the tap used in a CATV network. The effect of this splitting is to share content between small numbers of homes with some loss in optical power caused by the splitting process. This splitting is limited by the amount of optical power that must be provided to the receiver module in the Optical Network Unit at each home.

Premises Point of Presence or ONU

Each house requires a local interface be installed to provide the conversion process between the optical fiber and the copper-based medias that are used by the devices in the home.

Figure 7 shows a typical Optical Network Unit (ONU), which is mounted on the outside of a house. The ONU will contain circuit modules that convert the signaling delivered on the fiber optic cable coming to the house into various forms of copper media. For example, CATV signals will be converted to coax, telephone will be converted to unshielded twisted pair with an RJ11 connector and data will be converted to CAT5 unshielded twisted pair with an RJ45 connector for Ethernet. Should lifeline telephone service be required then a small UPS, Uninterruptible Power Source, will be placed inside the house to supply power to the telephones should commercial power fail.

Figure 7

Technical Direction

Fiber optic technology continues to push further into the CATV cable plant with the latest technology supplying FTTP and FTTB. Many companies and cities are evaluating all approaches for building a new CATV system and finding that the all fiber approach has a similar cost to the HFC configuration. This is particularly true where a new cable plant must be built in a green space area where all new cable and components must be installed.

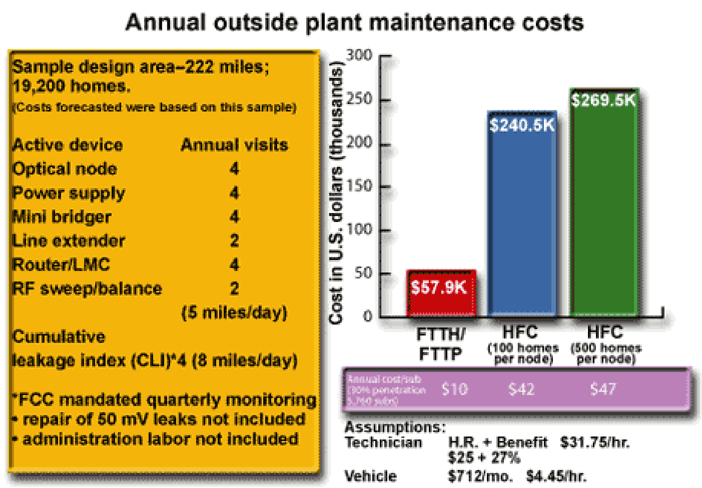
The use of fiber optics has the potential to provide almost unlimited bandwidth that is capable of supporting all applications in the future. At some point FTTP will become the dominate communications system as prices continue to drop on fiber optic components and the systems continue the migration from analog to digital-based signaling.

Return to Appendices

Conclusion

FTTP technology appears to be the direction for communications links over the last-mile. Decreasing cost of components, new technical innovations and a shift toward all digital signaling support building these types of systems. Current studies have looked at the cost of building a FTTP cable plant compared to an HFC cable plant and find that HFC enjoys a price advantage in the residential market. A recent article states that FTTP costs 10 to 15 percent more to install than a similar HFC system [6] with a typical return on investment of three to five years.

Many of the cable companies have completed 95 percent of the rebuild of their systems using HFC technology [5] and do not see an economic advantage to changing their current infrastructure. Others believe the business case is more favorable for smaller towns where a longer return on investment may be tolerated. Provide the common services of voice, video and data to the residence with services to the business community and the business case becomes more favorable [5]. For the cable companies, the leap to the business customer is not a step that most are ready to take.



This leaves the target market for FTTP technology the municipal groups or new systems being built in green space areas and upper end planned communities, these areas typical have a higher penetration rate. Declining costs for FTTP systems have come to "within 10 to 15 percent of HFC costs…[for] 100-125 home nodes [6]." However, construction costs for the cable plant is only one part of the overall cost of ownership. "The cost of maintaining an FTTH/FTTP network is far less-perhaps as much as four to eight times- than the maintenance costs for HFC [6]." The adjacent Figure 8 shows a comparison of outside plant costs for typical HFC systems and a comparable FTTP system.

Beyond greater capacity, "lower maintenance costs, not just new services, are driving Verizon toward a fiber future. Verizon already spends north of $6 billion a year maintaining its existing network, equating to about half of its annual capital expenditures [6]." Organizations must consider the total cost of ownership as part of their overall business plan. As these costs continue to be analyzed more companies will be moving to fiber optic systems.

Technology Implementation

Equipment cost	substantial
Monthly cost, video	$30-$80
Monthly cost, HS data	$40-$60
Link distance	2-40 Km
Line of sight required	no
Individual link speeds	substantial
Implementation time	years
Support effort	low
Support frequency	as needed
SNMP-based monitoring	yes
Video support	yes

Return to Appendices

IP telephony support	yes
Internet access support	yes
Support most LAN protocols	no, IP only

Usage Analysis

Short distance p-p	yes
Long distance p-p	yes
Short distance multipoint	yes
Long distance multipoint	yes
Mesh configurations	yes

Interesting Websites

The vendor and organization Websites are shown in alphabetical order may provide additional information:

www.alloptic.com
www.cedmagazine.com
www.c-cor.net
www.ftthcouncil.com
www.harmonicinc.com
www.opticalsolutions.com
www.quantumbridge.com
www.terawave.com
www.wave7.com

Figures

[1] White Paper: Last-mile Link Architecture. Wave7 Optics, 2/14/2002. Based upon the drawing shown under Physical Topology on page 2 of the document.

[2] Figure 2 is based upon a concept illustrated on the Website for Alloptic. The Website can be found at www.alloptic.com.

[3] Based upon a concept illustrated on the Website for Optical Solutions, Inc. www.opticalsolutions.com

[4] This illustration is based upon a product manufactured by Harmonic Lightwave. www.harmonicinc.com/view_ban_product_group.cfm

[5] This illustration is based upon a product manufactured by Wave7 Optical. http://www.wave7optics.com/core.html

[6] This illustration is based upon part of a drawing in the White Paper: Last-mile Link Architecture. Wave7 Optics, 2/14/2002. Based upon the drawing shown under Physical Topology on page 2 of the document.

[7] This illustration is based upon a concept illustrated on the Website for Alloptic. The Website can be found at www.alloptic.com.

[8] CED magazine, Filling Up on fiber by Jeff Baumgartner. March 2004, pages 18 through 24. http://www.cedmagazine.com/ced/2004/0304/03a.htm

Return to Appendices

References

[1] CED Magazine. February 2003. http://www.cedmagazine.com/ced/2003/0203/02a.htm. Fiber-to-the-home blazes an evolutionary path.

[2] Typical node controller. http://www.wave7optics.com/core.html

[3] Typical fiber headend services interface. http://www.opticalsolutions.com/main_s.shtml

[4] Typical HFC fiber optic transmitter. www.harmonicinc.com/view_ban_product_group.cfm

[5] Fiber-to-the-where? CED, Communications Engineering & Design, March 2, 2002 edition. www.cedmagazine.com/ced/2002/0302/03d.htm

[6] CED magazine, Filling Up on fiber by Jeff Baumgartner. March 2004, pages 18 through 24. http://www.cedmagazine.com/ced/2004/0304/03a.htm

Return to Appendices